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ORIGINAL ARTICLES.

Fossils from the Blue Mountains of Jamaica.

By C. T. TRECHMANN, D.Sc., F.G.S.

(PLATE XVIII.)

INTRODUCTION.

MR. G. M. STOCKLEY, F.G.S. in 1925 made the interesting discovery of fossils near the top of Blue Mountain Peak, the highest summit in Jamaica, at the considerable altitude of about 7,000 feet. Unfortunately the material he collected was lost on the way down by a horse slipping and throwing his fossils down a ravine. He told me, however, that he was almost sure there was a species of *Inoceramus* among them. Dr. C. A. Matley, F.G.S. collected some specimens at the same locality a year or two later. On looking over his collection, however, I could not find any fossils which might fix beyond doubt the age of the beds. During a recent visit to Blue Mountain Peak I was able to spend enough time at the locality to make a small collection of fossils which I now endeavour to describe.

The fossiliferous bed occurs about 300 feet below, and a little to the south-west of, the actual Blue Mountain Peak and comprises some 30 feet of grey calcareous rather concretionary and splintery shales which dip at a steep angle apparently to the south-west. The shales are but little metamorphosed and the fossils are scarce and fragmentary and often present as crushed casts.

The actual summit of Blue Mountain, 7,335 feet, is formed of purple conglomerate probably in part an agglomeratic volcanic ash, not especially hard and but little altered ; similar in appearance to the so-called Trappean conglomerates that occur associated with Cretaceous beds at lower altitudes in different parts of the island. A more detailed examination of the formations at the highest altitudes in the eastern part of Jamaica shows that they do not by any means consist entirely of " metamorphosed series " as Sawkins indicates on his map.[1] On reading the memoir by Sawkins however one finds that his " metamorphosed series " includes metamorphosed shale, sandstone, and conglomerate with dykes of intrusive diorite, syenite and granite.

To the north-east of Kingston at Guava Ridge there is a large mass of quartz-porphyry apparently forming part of a sill. This rock from a distance has a decidedly bedded appearance and comprises part of the area mapped as " metamorphosed series " by Sawkins. He appears to have held the view that it was a case of metamorphism " in situ " of a sedimentary series with preservation of the bedding.

To the east of Blue Mountain Peak on both the northern and southern side of the range at Mooretown and on the Plantain Garden River there are outcrops of Rudist limestones, which I have little doubt might be traced across the divide if a search were made. The original locality of the Rudist genus *Barrettia* was a limestone up the Back River in the direction of Blue Mountain Peak at an altitude of probably four or five thousand feet in the Blue Mountain complex. The locality has apparently never been seen in recent times.

The track to Blue Mountain Peak shows good exposures at lower levels of the Carbonaceous Shale or Richmond Formation. Above the Yallahs River Valley there is a considerable thickness of thinly bedded dark shales of this series, as usual very unfossiliferous except perhaps for obscure plant remains. These seem to be a Flysch-like development of the lower and possibly middle Eocene. Higher up, above Abbey Green to the south-west of Blue Mountain Peak at about 5,000 feet a thick bed of compact rather altered limestone is met with, and belongs apparently to the Carbonaceous shale series. This limestone shows traces of organisms; a thin slice reveals brown translucent volcanic fragments with ferruginous and magnetite inclusions. These fragments are irregular in size and shape and have much eroded edges, some of them are encrusted with calcite in the form of ooliths or possibly Calcareous Algae. Other fragments seem to be ooliths and bits of spines or shell or possibly foraminifera all embedded in a matrix of calcite. Not much definite structure can be made out, as the rock is altered and sheared. Other limestones occur in the Blue Mountain complex, for instance near Guava Ridge, in which no trace of fossils can be detected, apparently the result of metamorphism.

The zig-zag road which leads from Hope Gardens above Kingston up to the military cantonment of Newcastle at 3,974 feet and further on over the pass at Hardwar Gap to the north coast offers an instructive section of a portion of the rocks that form the Blue Mountain range. The arrangement of the various beds of coarse or fine purple and grey conglomerates and sandstones with occasional

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[1] " Reports on the Geol. of Jamaica," *Mem. Geol. Survey*, part ii, 1869.

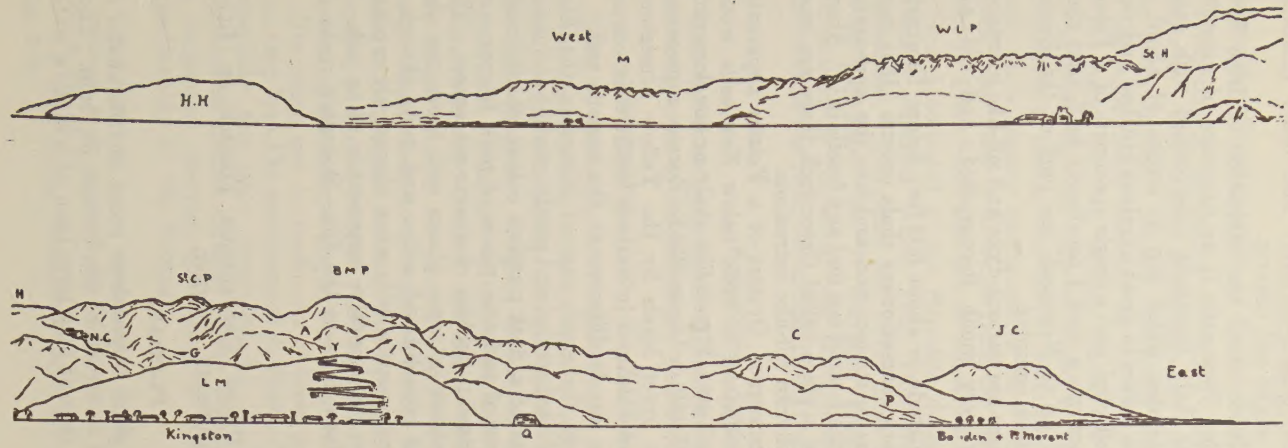

FIG. 1.—Profile sketch of the south-east part of Jamaica, made from the deck of a steamer in Kingston Harbour. H.H. Healthshire Hills, west of the entrance of Kingston Harbour (white limestone). M. White limestone plateau in the direction of Mandeville. W.L.P. White limestone plateau cut up into " cockpits ". St. H. Stony Hill (white limestone with granite below and behind it). N.C. Newcastle 3,974 ft. on a ridge of Blue Mountain rocks. H. Hardwar Gap, 4,079 feet. St. C.P. St. Catherine Peak, 5,034 feet (Carbonaceous shales ?). G. Direction of Guava Ridge, 2,765 feet. L.M. Long Mountain, east of Kingston, with a zig-zag road up it (white limestone, oligocene, with the Gasteropod Orthaulax near the top). Q. Quarry in white limestone. A. Abbey Green. B.M.P. Blue Mountain Peak, 7,335 feet (cretaceous shales and conglomerates). Y. Direction of Yallahs River Valley. C. Cuna Cuna Mountain (Blue Mountain rocks). P. Direction of Plantain Garden River. J.C. John Crow Hills about 2,000 feet (white limestone). Length of section about 40 miles.

shales and limestones and quartz-porphyry and other intrusions appears to be what one might call chaotic.

At about 2,000 feet altitude near the habitation of Irish Town and about 1,800 feet below Newcastle is an exposure of some 100 feet of dark grey nodular shaly limestone interbedded with sandstones and fine conglomerates which dip at angles of about 45 degrees. The genus *Ostrea* occurs in great numbers crushed and very badly preserved, but I collected also a single specimen of a *Velates* in this bed. This find confirms a view I previously held, that these Oyster beds on the road up to Newcastle are part of the Eocene series of the Blue Mountain complex.

Further up the road there are various dyke and sill-like intrusions of quartz-porphyry now very much decomposed, and red and purple conglomerates.

At about 3,200 feet altitude or about 600 feet below Newcastle a bed of well stratified dark concretionary shale occurs. It is more quartzitic than calcareous in composition and has the appearance of a Cretaceous shale though I could not find any fossils in it. Above Newcastle on the road to a place called Greenwich there are more exposures of quartz-porphyrite sill-like intrusions.

The presence among numerous Oysters of a *Velates* apparently the well known *V. schmideliana* in beds below Newcastle would tend to show that we have here a Flysch-like shaly or conglomeratic equivalent of part of the Middle or Lower Middle Eocene, represented elsewhere in Jamaica at lower levels by the Yellow Limestone. This bed yields *Velates schmideliana* in various localities in central and west Jamaica but is less fossiliferous at the eastern end.

Below Gordon Town to the north east of Kingston the Blue Mountain rocks consist of hard welded and partly crushed and much slickensided conglomerates of a dark purplish colour, chiefly made up of fragments of all sizes of andesite, pieces of pink felspar, and limestone almost marmorized; pebbles of quartz are scarce. The series is very thickly bedded in some places and there are also apparently thick beds of consolidated ashes and tuffs though I have noticed that the conglomerate beds when thoroughly crushed and smashed up take on the deceptive appearance of an ash. I never saw any trace of lava flows in the Blue Mountain rocks of Jamaica.

DESCRIPTION OF THE UPPER CRETACEOUS FOSSILS OF BLUE MOUNTAIN SUMMIT.

PLANTAE.

Obscure carbonaceous plant impressions occur in the shales of Blue Mountain Peak, but no structure can be seen in them. They suggest however that the deposit may have been of a shallow water nature.

FORAMINIFERA.

Resembling *Omphalocyclus* or *Pseudorbitoides*. Pl. XVIII, Fig. 16.

Foraminifera measuring up to 6·5 mm. in diameter are rather common. The outline is circular and one side is flat or concave, the other strongly convex, becoming almost conical. Specimens of the same fossils collected by Dr. C. A. Matley have been placed in the hands of Prof. Morley Davies for examination and indeed the identification can only be settled by experts in this group. The disposition of the curving lines of chambers however in my specimens seem on a cursory examination very like those of *O. macropora* Lamk, described by Douvillé from the Maestrichtian east of Kampa Jong in Tibet,[1] but that is a bi-concave form. It may be related to a form I collected in the *Barrettia* limestone at Green Island in Western Jamaica which Prof. Douvillé named *Pseudorbitoides trechmanni*.[2] The outer test in the Blue Mountain examples seems to be perforate. Dr. T. Wayland Vaughan writes me that the Foraminiferon I collected near Blue Mountain Peak is a new genus and that he has received similar forms from the Cretaceous of Cuba.

Echinoderm Spines.

Traces of these occur in the Blue Mountain shales but are so small and meagre as to be generically indeterminable.

Paracyathus (?) sp. Pl. XVIII, Figs. 11 and 12.

Casts of specimens of a small simple coral apparently referable to this genus occur often in small clusters together with *Serpula* tubes, small *Turritellae*, *Pseudorbitoides*-like foraminifera etc., in the Blue Mountain shales. Height of one specimen, Fig. 12, is 6 mm., the diameter of the calyx 5·5 mm. The wall is rather thick, externally costate, the costae probably 40–45 in number, are rather broad; the grooves between them deeply and sharply cut. Costae seem to correspond to the larger septa and the septa seem to be unequal in size. The base of attachment is rather broad, tending to spread in some specimens; the columella is strong and formed of the inner edges of the septa twisted together.

Not much can be made out of these poorly preserved examples but they look like specimens of *P. lloydi*, *P. thomi*, or *P. kayserensis*, especially the last; described by T. W. Vaughan[3] from the Cannonball marine member of the Lance formation in N. Dakota, a formation referred apparently to the highest Cretaceous or questionably to the Eocene.

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[1] *Pal. Ind.*, N.S., vol. v, mem. 3, 1916, p. 35, pl. xiii, figs. 4 and 5.

[2] *Compte rendu sommaire des Séances de la Soc. Géol. de France*, Dec. 18, 1922, p. 203, fig. 1.

[3] *U.S. Geol. Survey*, Professional Paper, 128–A, 1920, pp. 62 and 63, pl. x, figs. 3–5*b*.

Serpula lineata Weller. Pl. XVIII, Fig. 15.

Two or three nearly straight tubules, one of them 17 mm. long and 2·5 mm. wide showing faint concentric growth rings on the cast closely resemble this fossil figured by L. W. Stephenson[1] from the Snow Hill group of Neuse River, N. Carolina; the upper part of the *Exogyra ponderosa* zone; Emscherian or Campanian.

Serpula cretacea Conrad.

Small nests of slightly curved tubules occur also in the shales of Blue Mountain summit. The shell has been rather thick and the impression in the rock shows well marked regular concentric growth lines. They resemble rather closely specimens figured by L. W. Stephenson on the plate just referred to and from the same horizon, figs. 1–10.

MOLLUSCA.

Arca (*Barbatia*) sp. Pl. XVIII, Fig. 13.

An internal cast of a right valve, 8·5 mm. long and 5 mm. high is well arched and has a broad beak. The surface is decorated with 18 or 20 ribs, stronger posteriorly than anteriorly, which radiate from the beak region to the anterior and lower margin. Though poorly preserved it recalls casts of *A.* (*Barbatia*) *carolinensis* Conrad from the Upper Cretaceous of the Neuse River, North Carolina[2] figured by L. W. Stephenson.

Inoceramus cf. *balticus* Boehm. Pl. XVIII, Figs. 1 and 2.

A small specimen, Fig. 2, with both valves conjoined, of which a squeeze was made, has both valves inflated in the umbonal region, the right less so than the left. The beaks are very anteriorly situated and the umbones are small. Ribs number about fifteen on the right valve and are rather fine and regular near the beak but irregularly grown and foliaceous towards the margin. The left valve is much obscured but the ribs become flattened and foliaceous near the margins and show a tendency to come off from the sides of other ribs. The length is 19 mm. height 13 m.m. and thickness of both valves about 13 mm. Fig. 1 is a squeeze of the apical part of a right valve with 8 or 9 fairly regular rather foliated concentric ribs with broad concave interspaces.

There can be no doubt that these small shells are some species of *Inoceramus* and their outline suggests that of the young portion of *I. balticus* Boehm that occur in Cretaceous shales about 800 feet below a *Barrettia* limestone in St. Ann's Great River valley near the north coast of Jamaica.[3]

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[1] *N. Carolina Geol. and Econ. Survey*, vol. v, pt. 1, 1923, p. 70, pl. ix, figs. 13 and 14.

[2] *N. Carolina Geol. and Econ. Survey*, vol. v, pt. 1, 1923, p. 119, pl. xxii, figs. 4 and 5.

[3] GEOL. MAG., Vol. LXIV, Nos. 751 and 2, Jan. and Feb., 1927, p. 52, Pl. I, Fig. 6.

Inoceramus sp. Pl. XVIII, Fig. 3.

A fragment of a large shell with 5 regular undulating ridges is apparently a portion of an *Inoceramus.*

Camptonectes sp. Pl. XVIII, Fig. 7.

Some valves of a small fragile flattened *Pecten* occur in the Blue Mountain shales. A squeeze of a right valve, Fig. 7, is 16 mm. high and 12 mm. wide, the beak is pointed and sharply differentiated from the ears both of which are well developed, the posterior rather more elongate than the anterior and both decorated with fine ribs crossed by growth lines.

The surface of the valve bears 11 or 12 faint sharp grooves which diverge from some distance below the beak and pass to the margins, and has a series of close-set very fine divaricating ribs which commence just below the beak and diverge from a median line to the anterior and posterior margins, extending also over both ears. Near the beak the divaricate ribs are replaced by faint grooves of growth.

The divaricate ribbing of this *Pecten* recalls that of *C. striatopunctatus* Röm, and of *C. curvatus* Gein, the latter common in Cretaceous shales at Providence near Port Antonio and near Catadupa[1]; but the present shell is longer with respect to its width and has a more delicate ribbing.

Camptonectes cf. *curvatus* Gein.

A specimen having the outline and ornamentation of this species was seen but unfortunately broke up ; and I have two or three broken casts of other specimens. They resemble specimens from the Cretaceous shales at the localities just mentioned.

Antillocaprina (?) sp. Pl. XVIII, Figs. 4, 5, and 6.

Figs. 4 and 5 show the cast of the interior and a squeeze of the outside of a lower or conical valve of a young Rudist allied to a genus I called *Antillocaprina.* The specimen Fig. 4 shows the smooth outer layer near the apex which is rather twisted and the substance of the middle layer formed of a mass of parallel tubules which near the margin divide up into twos or threes by the intercalation of smaller and shorter tubules. The specimen shows the space occupied by the median tooth of the lower valve and apparently the sockets of the two teeth of the upper valve situated near the rather straight hinge line. A squeeze of the outside of the same valve, Fig. 5, shows the rather twisted conical apex and the smooth exterior layer with four or five prominent irregular foliated growth lines.

Among the fossils I saw at Blue Mountain Peak but could not bring away except in fragments were some crushed valves 6 or 8 inches in size having the curved and inrolled outline and internal structure made up of long packed tubules also recalling this genus and closely resembling forms which are seen in the Cretaceous shales along the Cambridge–Catadupa railway line.[1] Nothing of the internal structure except the tubules could be seen. Fig. 6 represents a crushed cornucopia-like right or left valve having the same tubular structure. All these specimens are too badly crushed to identify specifically, but they differ from *Antillocaprina* (*Caprinella*) *occidentalis* Whitfield, which occur in the Cretaceous limestones at Catadupa and Logie Green.

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[1] **Geol. Mag., Vol. LXIV, Nos. 751 and 2, Jan. and Feb., 1927, Pl. III, Figs. 7 and 8.**

Corbula sp. Pl. XVIII, Fig. 14.

A right valve of a *Corbula* is 5 mm. long and 3.5 mm. high and is well arched. The beak is broad and rather low and an angular ridge runs from behind it to the lower posterior margin which is somewhat produced. The surface is decorated with fine regular concentric growth lines, the portion towards the beak being nearly smooth.

It bears a somewhat distant resemblance to *C. sub-gibbosa* Conrad [2] from the Snow Hill calcareous members of the *Exogyra ponderosa* zone of N. Carolina, but the beak is apparently broader in the Jamaica form and more forwardly directed.

Corbula sp.

A single imperfect very small and strongly arched right valve is not unlike a *Corbula* that I collected in some numbers 900 feet below the *Barrettia* limestone at St. Ann's Great River, and compared with *C. parsura* Stoliczka.[3] It is 3·5 mm. high and has been about the same length. Traces of fine wavy growth lines are seen near the lower anterior margin but the ribs are finer and the beak narrower and higher than in the St. Ann's Great River specimens.

Cerithium cf. *Aguilerae* Boehm. Pl. XVIII, Fig. 10.

A fragment of about 7 whorls, the last whorls missing and the early spire obscure has a well sunken and rather wavy suture line. The whorls increase rather rapidly in size and are nodose with coarse upright or very slightly inclined ribs which broaden out towards the anterior part of each whorl. The ribs are rather irregular in size and six of them are seen on the exposed side of the last whorl. They are crossed by a number of irregular spiral ridges, 20 or 25 of them on the last whorl, some fairly conspicuous, others only seen with a lens, crossing both the ribs and the sulci between them. Length 17 mm., width of last whorl 7 mm.

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[1] Geol. Mag., Vol. LXIV, Nos. 751 and 2, Jan. and Feb., 1927, p. 59, Pl. II, Fig. 10, and Pl. IV, Fig. 6.

[2] *N. Carolina Geol. and Econ. Survey*, vol. v, pt. 1, 1923, p. 334, pl. lxxxvi, figs. 18 and 19.

[3] Geol. Mag., Vol. LXIV, Nos. 751 and 2, Jan. and Feb., 1927, p. 62, Pl. IV, Figs. 21–22*a*.

This shell seems to occur rather commonly in the Blue Mountain shales. It resembles rather closely the young stages of *C. aguilerae* Boehm from the Lower Senonian with *Coralliochama G. boehmi*[1] from Cardenas, Mexico though in the figures of this form the young shell is broken away. The Jamaican form like the Mexican, seems to have no enlarged varices on the whorls.

Turritella spp. Pl. XVIII, Fig. 9.

A small *Turritella*, 5 whorls of which are 9 mm. long, has slightly convex sides, and a sharply but faintly impressed rather inclined suture. It bears about 8 fine spiral ridges on each whorl which vary much in size. The strongest ridge occurs about a third of the height above the suture and is slightly tuberculated, below and above this the side is slightly hollowed out and has fainter but variable ridges, like thread lines. In size and shape it rather resembles *T. haresi* described by T. W. Stanton[2] from the Cannonball marine member of the Lance formation.

Another *Turritella* 11 mm. long has flatter sides and sharply cut shallow level sutures and about 10 ridges on each whorl fine and distinct but variable in strength. It bears some resemblance to *T. pointensis* L. W. Stephenson[3] from the *Exogyra costata* zone. of the Peedee formation of North Carolina.

Lunatia sp. Pl. XVIII, Fig. 8.

The cast of a rather solid naticoid shell 18·5 mm. high and 16 mm. wide shows 6 whorls, the sides rounded and apparently smooth and the suture well sunken with the whorls rather platformed below it. The basal and umbilical portion is not preserved. It is slightly larger and has a higher spire than *L. obliquata* Hall and Meek, from the Cannonball marine member of the Lance formation. It also recalls *L. larteti* Boehm figured by E. Spengler[4] from the Upper Cretaceous of Tharia Ghat in Assam.

Actaeonella (*Trochactaeon*) cf. *variabilis* Böse.

A cast of an *Actaeonella* about 22 mm. in length which unfortunately broke up was very similar to the above species from the Senonian of Cardenas, Mexico.[5] Numerous *Actaeonellae* of this and allied species occur in the Cretaceous limestones in various parts of Jamaica but have not been published yet.

Correlation.

The small fauna from Blue Mountain Peak does not afford much evidence for correlation. I could see no trace of Ammonites in these shales, and several fossils that occur commonly in the Cretaceous shales at lower levels are conspicuously absent. The *Inocerami* which resemble small specimen of *I. balticus* seem to indicate the high Senonian but they may be dwarfed and impoverished adult forms marking a still higher horizon. *Pecten* (*Camptonectes*) *curvatus* is a species with a considerable vertical range in the Upper Cretaceous. The *Rudistae* though specifically indeterminable are evidently the same as forms that occur in the Catadupa shales with *Roudaireia* and other shells and are probably Maestrichtian.

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[1] *Bol. del Inst. Geol. de Mexico*, Num. 24, 1906, p. 70, pl. xv, figs. 24 and 27.

[2] *U.S. Geol. Survey*, Profess. Paper, 128–A, 1920, p. 37, pl. vi, fig. 12.

[3] *N. Carolina Geol. and Econ. Survey*, vol. v, part 1, 1923, p. 368, pl. xci, figs. 4 and 5.

[4] *Pal. Ind.*, New Series, vol. viii, mem. 1, 1923, pl. ii, fig. 27.

[5] *Bol. del Inst. Geol. de Mexico*, Num. 24, 1906, p. 90, pl. xviii, figs. 26–34.

The fauna also shows affinity, for instance in the *Serpulæ*, with the Upper Cretaceous of N. Carolina and in its small corals with the Cannonball marine member of the Lance formation of western N. and S. Dakota. It goes to indicate that the Cretaceous shale and limestone fossils of Jamaica are, except for a few almost world-wide species, more American in their affinities than Old World. On the other hand the Eocene faunas in Jamaica (Yellow Limestone) and to a less extent in Barbados (Scotland beds) are more African, European and Indian (Sind) in affinity than North and South American.

As I have said in a previous paper, this does not seem to lend much encouragement to the westerly drift theory of America from Africa.

Eocene Fossils from 1,800 feet below Newcastle.

Ostrea cf. *sparnacensis* Defr. Pl. XVIII, Fig. 18.

A rather flat left valve resembles specimens that occur in the Yellow Limestone at Spring Mount and elsewhere in Jamaica which I compared with this species.[1] It is 46 mm. long and 24 mm. wide and is decorated with coarse growth lines.

Ostrea (*Pycnodonta*) cf. *cymbiola* Desh. Pl. XVIII, Fig. 17.

A right valve 78 mm. high, 54 mm. wide, and 42 mm. deep has an inflated shell with the beak including the surface of attachment strongly arched and bent forwards. It recalls in shape, but is larger than *P. cymbiola* Desh. from the Bartonian of Le Fayel in the Paris Basin but is larger than the Paris specimen figured by Cossmann and Pissarro (*Iconographie*, pl. xlii, fig. 135–1).

A poorly preserved and distorted flattish left valve, also from the Oyster bed below Newcastle, probably belongs to the same species.

Velates cf. *schmideliana* Chemn. Pl. XVIII, Fig. 19*a* and *b*.

A small poorly preserved *Velates* 28 mm. long, 22 mm. wide, and 13·5 mm. high was found in the beds below Newcastle. Its shape and growth lines closely resemble those of some specimens of this species which occurs in the Yellow Limestone in Jamaica. The lowness of its spire also rather recalls that of *V. tibeticus* Douvillé[2]

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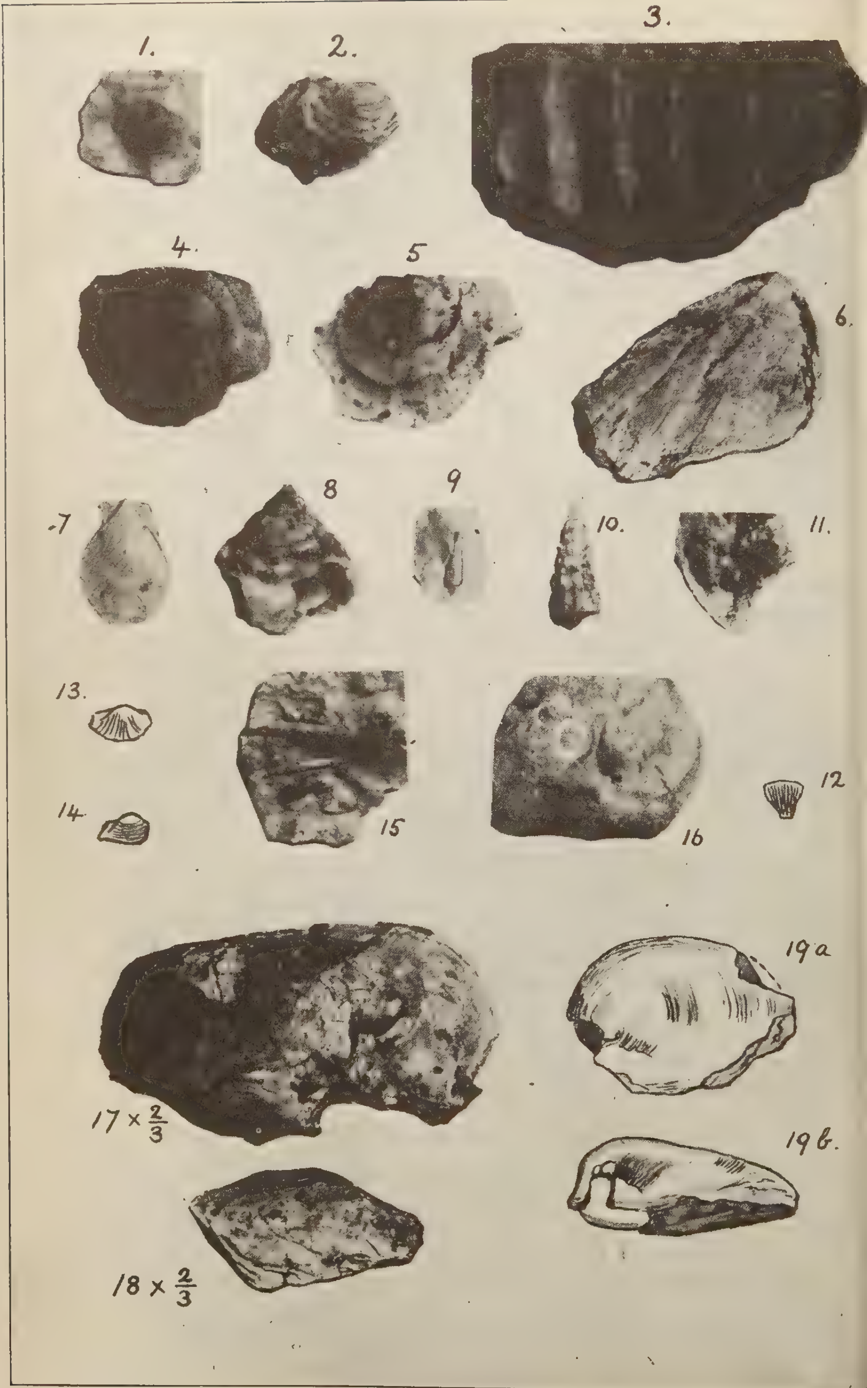
[1] Geol. Mag., Vol. LX, No. 710, Aug., 1923, p. 362, Pl. XVI, Figs. 2 and 3.

[2] "Le Crétacé et l'Eocène du Tibet central," *Pal. Ind.*, n.s., vol. v, mem. 3, 1916, p. 25, pl. viii, figs. 1*a*–3*b*.



Fossils from the Blue Mountains of Jamaica.
1–16, Blue Mountain Peak (Cretaceous); 17–19, Below Newcastle (Eocene)

rom Central Tibet which occurs in a group of fossils placed by Douvillé in the Cretaceous but which I was informed in the Geological Survey Office in Calcutta is now referred to the Ranikot series. It differs from a fragment of a *Velates* I once collected in the conglomerates of the Carbonaceous shales or Richmond formation at Port Maria on the north coast of Jamaica and which I compared with *V. noetlingi* Cossm. and Pissarro[1] from the Upper Ranikot Series. If as I think, the present specimen is identical with *V. schmideliana* it would seem to indicate that some of the dark shales and conglomerates in the Blue Mountain complex are a Flysch-like equivalent of the Yellow Limestone and are of Cuisian or Lutetian age.

EXPLANATION OF PLATE XVIII.

All specimens are represented natural size unless otherwise stated.

FIG.

1. *Inoceramus* cf. *balticus* Boehm. Squeeze of the apical part of a small right valve. Shales 300 feet below Blue Mountain Peak, Jamaica. Page 486.
2. Ditto. Squeeze of two small valves conjoined, showing the right one. Same locality.
3. *Inoceramus* sp. Squeeze of a fragment of a ribbed valve. Same locality. Page 487.
4. *Antillocaprina* (?) sp. Natural cast of interior of a lower or conical valve of a young specimen showing hinge teeth. Same locality. Page 487.
5. Ditto. Squeeze of exterior of the same valve. Same locality. Page 487.
6. Ditto. A crushed cornucopia-like either left or right valve. Same locality. Page 487.
7. *Camptonectes* sp. Squeeze of a right valve. Same locality. Page 487.
8. *Lunatia* sp. Squeeze, the basal and umbilical portion not preserved. Same locality. Page 489.
9. *Turritella* cf. *haresi.* Stanton. A squeeze. Same locality. Page 489.

0. *Cerithium* cf. *aguilerae.* Boehm. A squeeze, the last whorls missing. Same locality. Page 488.

1. *Paracyathus* sp. A squeeze of impressions of two specimens in the shale. Same locality. Page 485.

2. Ditto. Sketch of the outside of a corallum taken from a squeeze. Same locality.

3. *Arca* (*Barbatia*) cf. *carolinensis.* Conrad. A sketch of a right valve. Same locality. Page 486.

4. *Corbula* sp. Sketch of a right valve. Same locality. Page 488.

5. *Serpula lineata* Weller. Squeeze of impressions of tubules in the shale. Same locality. Page 486.

6. A *Foraminiferon* resembling *Omphalocyclus* or *Pseudorbitoides.* Slightly enlarged. Same locality. Page 485.

7. *Ostrea* (*Pycnodonta*) cf. *cymbiola.* Desh. From limestone beds 1,800 feet below Newcastle, Jamaica. A right valve, two-thirds natural size. Page 490.

8. *Ostrea* cf. *sparnacensis.* Defr. Same locality. A left valve, two thirds natural size. Page 490.

9*a* and *b*. *Velates schmideliana.* Chem. Same locality. A sketch, from above and from side showing the spire. Page 490.

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[1] *Pal. Ind.*, N.S., vol. iii, mem. 1, 1909, p. 76, pl. vi, figs. 24–7, and GEOL. MAG., Vol. LXI, No. 715, Jan., 1924, p. 10, Pl. I, Fig. 7.

Remarks on the Attachment of *Dictyonema flabelliforme* (Eichw.).

By O. M. B. Bulman, Ph.D., D.I.C., A.R.C.S.

Introduction.

THE specimen to be described is from part of the McKenny Hughes Collection, preserved in the Sedgwick Museum, and was without any indication of horizon or locality. It is a slab of hard, light-grey, spotted shale, containing numerous examples of *Dictyonema flabelliforme* (Eichwald). The matrix is quite unlike any *Dictyonema* Shale known to the writer from extra-British localities, and from the general habit of the graptolites, supported by the lithology of the shale, the specimen is considered to be from some locality in Wales. In the view of Dr. G. L. Elles, who has examined the specimen, it may be part of a collection of *D. flabelliforme* made by McKenny Hughes from the Portmadoc district. A remarkable feature is shown in the proximal ends of three of the rhabdosomes, where the sicula terminates, not in a nema, but in a little tuft of root-like fibres.

Description of Material.

1. *Diagnosis of Species* :—

Rhabdosome having a length–breadth ratio of 1, 4 : 1 ; stipes average 8–9 per cm. ; dissepiments, irregular in spacing and direction of growth, 9–10 per cm.

Dictyonema flabelliforme forma typica Brögger, 1882 (as accepted in *Mon. Brit. Dendr. Grapt.*, Pal. Soc., pt. i, 1927, p. 24).

2. *Specimen* 37*b* *and Counterpart* (Fig. 1).—Total length of rhabdosome, 1 cm. ; maximum breadth of rhabdosome, 1 cm. ; length of sicula, 1–2 mm. approx.

As shown in the figure, the outline of the sicula can be traced distinctly inside the stem, and as far as may be determined, secondary chitin has been deposited principally around the apical portion, producing a very short, hourglass-shaped stem. From the sicula (s) arises the lateral bud (I°), from the right side of which the first bitheca (i°) is produced ; of the other descendants of I°, only the hydrotheca 1^1 and its parent budding individual I^1 can be traced. The details, however, are sufficient to demonstrate that the thecal structure of the proximal end is identical in general principle with that of the normal *D. flabelliforme*.[1]

From the expanded base of the stem, about six " root fibres " take their origin and attain in some cases a length of over 3 mm.

It may further be noted that from two of the proximal branches, slender fibres are given off, which join the main tuft developed from the stem.

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[1] See *Mon. Brit. Dendr. Grapt.* (*Pal. Soc.*), pt. i, 1927, pp. 18 et seq.

3. *Specimen* 37*c* (Fig. 2).—Total length of rhabdosome, 3·3 cm.; maximum breadth of rhabdosome, 2·3 cm. (estimated).

The sicula and structural details are obscure, but "root fibres", comparatively few in number, are clearly visible.

4. *Specimen* 37*a and Counterpart* (Fig. 3).—Length of sicula, 1·4 mm. approx.; breadth at aperture, 0·35 mm. approx.

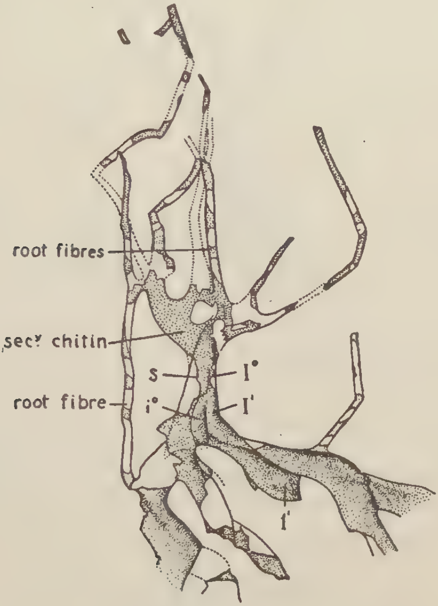

Fig. 1.—*Dictyonema flabelliforme forma typica*, specimen 37*b*. Proximal end, × 13·5, showing outline of sicula (s) within the stem, lateral bud (I°), budding individual (I^1), bitheca (i°), hydrotheca (1^1), with secondary chitin, "root fibres" and additional fibres from proximal branches. Aperture of sicula, and other dotted outlines, obtained from the counterpart.

There is an indication of the lateral bud (I°), with fine growth-lines, and of the general derivation from this of two of the primary branches, but the details are obscure. There is a strong suggestion here, also, of a development of additional "root fibres" from the initial portion of one of the primary branches, as already seen in Specimen 37*b*.

Discussion and Conclusions.

The fact that the material is beyond doubt referable to the species *Dictyonema flabelliforme f. typica* is of importance as showing that the nema may be superseded by the formation of a root during the lifetime of a single species (and that before the evolution of the stratigraphically highest variety). The suggestion that the genus might be subdivided according to whether the attachment is by means of a nema or a stem is obviously untenable, and proof is surely furnished of Lapworth's statement,[1] "diese Bildungen [stem, membrane, disc, or funicle] sind doch nur Varianten des Hydrocaulus, unter denen der Funiculus oder Nemacaulus nur ein Typus innerhalb der Reihe ist." It is not claimed that the demonstration of these structures in *D. flabelliforme* is in any way new, similar instances having been figured by Matthew[2] and Hahn,[3] but the retention, in these rooted forms, of precisely the same initial thecal structure can now, it is believed, be shown. If the

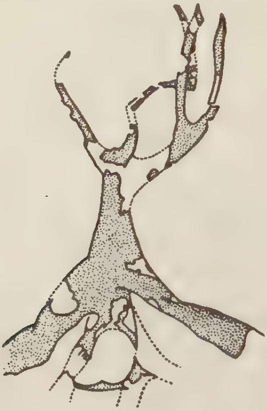

Fig. 2.—*Dictyonema flabelliforme forma typica,* Specimen 37*c*. Proximal end, × 13·5.

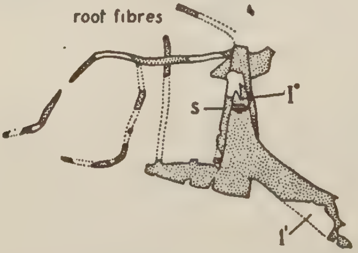

Fig. 3.—Specimen 37*a* and counterpart.

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[1] *Zeits. d.d. geol. Gesell.*, 1897, vol. xlv, p. 254.
[2] *Trans. New York Acad. Sci.*, vol. xiv, 1895, p. 272, pl. xlix.
[3] *Ann. New York Acad. Sci.*, vol. xxii, 1912, p. 148, pl. xxi.

material has been correctly localized, this is the first record of the rooted condition in *D. flabelliforme* in Europe.[1]

Another point of interest arises from a consideration of the accessory fibres developed from the proximal portion of the primary branches. These fibres have every appearance of having aided in the attachment of the rhabdosome, but are in themselves too slender to have given support in a *vertical* direction of growth, unless developed in much greater abundance than any of these specimens evidence. They would, however, have been of value in helping to anchor the rhabdosome if it maintained a *pendent*, or partly pendent, position. This to some extent supports the view that the rooted condition in this species was unaccompanied by any change in the direction of growth of the rhabdosome, which has always been considered pendent since Lapworth's pronouncement in " Die Lebensweise der Graptolithen ".[2] There seems to be evidence that an upright or vertical position was adopted by some later species of *Dictyonema*, and that it was possibly accompanied by a change in direction of growth of the bithecae.

Finally, the specimens supply the only stage (rooted, stemless *Dictyonema*) which had to be represented diagrammatically in a morphological series showing the derivation of the *Odontocaulis* condition (long, thecate stem) from the primitive nema attachment[3] and by completing the series, lend further support to the evolution there postulated.

A Note on the Classification of the Coal-measures.

By A. E. Trueman, D.Sc., F.G.S.[4]

DURING recent years considerable progress has been made in the study of the palaeontology of the Coal-measures. Attention has been directed to the flora, and to the marine and non-marine faunas. Although it is undesirable to attempt a complete revision of the classification of the Coal-measures until further work has been carried out, it may be useful to indicate certain conclusions which appear to be in accord with present knowledge.

The grouping of the Upper Carboniferous proposed by the late Dr. R. Kidston, based on the flora,[5] has been widely used in Britain and on the Continent, but much further research in nearly all coalfields will be needed before the exact boundaries of Kidston's divisions can be fixed. Whether certain of these divisions, after such further study, will prove to be adequate for stratigraphical purposes, is perhaps uncertain at present. It may be suggested, however, that a satisfactory scheme of classification must take into account the distribution of both fauna and flora.

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[1] Cf. *Mon. Brit. Dendr. Grapt.* (*Pal. Soc.*), pt. i, 1927, p. 18 ; and Westergård, *Lunds Univ. Årsskr.*, N.F., Afd. 2, Bd. 5, Nr. 3, p. 58.

[2] *Zeits. d.d. geol. Gesell.*, 1897, xlv, p. 254.

[3] Geol. Mag., 1928, vol. lxv, fig. 2, p. 341.

[4] The writer wishes to acknowledge the assistance he has received from the Government Grants Committee of the Royal Society, which has made possible the work on which certain of these conclusions are based.

[5] R. Kidston, *Proc. Roy. Phys. Soc. Edin.*, vol. xii, 1894, p. 183 ; " Division and Correlation of the Upper Portion of the Coal Measures " : *Quart. Journ. Geol. Soc.*, vol. lxi, 1905, p. 308.

In the Lower Coal-measures and Millstone Grit, the work of Mr. W. S. Bisat on the goniatite sequence has led to suggestions for a classification which promises to remove many difficulties in the correlation of those strata.[1]

In the course of recent studies in the sequence of non-marine Lamellibranchs it has been shown that about five zones can be traced in several coalfields of Britain,[2] and it is at least probable that after further study, especially in other coalfields, the Lamellibranchs will afford a basis for a satisfactory classification. There is already evidence that two major divisions of the Coal-measures appear to be separated by an important palaeontological break, which occurs between the Pulchra and the Phillipsii Zones.[3] This horizon marks the upper limit of the genus *Naiadites*, and of the numerous and varied species of *Anthracomya* which are characteristic of the lower zones, while the genus *Carbonicola* appears to have become very rare at about this horizon. Above that horizon the only non-marine shells are forms related to the group of *Anthracomya phillipsii*. This horizon is approximately that of the highest known marine band in the Coal-measures and while the absence of marine faunas in the higher beds is of course related to a change in conditions (and is therefore characteristic of a more or less restricted area) rather than to a change in fauna, it appears to be a circumstance of some importance in Britain and in several countries in Western Europe.

The position of the base of the Phillipsii Zone has not yet been precisely determined in most coalfields, on account of the scarcity of exposures and workings at about that horizon, but it appears to mark the most important palaeontological break which has so far been detected in the Coal-measures. It is suggested that it forms a basis for dividing the Upper Carboniferous into two major divisions, which may provisionally be known as the Upper Westphalian (Tenuis and Phillipsii Zones) and the Lower Westphalian (Similis-Pulchra, Modiolaris, and Ovalis Zones). It may be objected that the line occurs too high in the Upper Carboniferous to give a useful classification (except in southern Britain, where a large part of the worked Coal-measures lie within the Upper Westphalian). It may be pointed out, however, that while further subdivision of the Lower Westphalian would clearly be practicable, the significance of the widespread faunal break at the base of the Phillipsii Zone should be emphasized in any classification, and that this break is of greater importance than any which has been recognized at a lower horizon in the Coal-measures.

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[1] W. S. Bisat, "The Carboniferous Goniatites of the North of England": *Proc. Yorks. Geol. Soc.*, vol. xx, 1924, p. 40; "The Carboniferous Goniatite Zones of England, etc.": *Congrès. de Strat. Carb.*, Heerlen, 1927–8, p. 117.

[2] J. H. Davies and A. E. Trueman, "A Revision of the Non-Marine Lamellibranchs of the Coal Measures": *Quart. Journ. Geol. Soc.*, vol. lxxxiii, 1927, p. 210; E. Dix and A. E. Trueman, "Marine Horizons in the Coal Measures of South Wales": GEOL. MAG., vol. lxv, 1928, p. 356; S. G. Clift and A. E. Trueman, "The Sequence of Non-Marine Lamellibranchs in the Coal Measures of Notts and Derbyshire": *Quart. Journ. Geol. Soc.*, vol. lxxxv, 1929, p. 77; W. Hopkins, "The Distribution of the Mussel Bands in the Northumberland and Durham Coalfield": *Proc. Univ. Durham Phil. Soc.*, vol. viii, 1928, p. 1.

[3] A. E. Trueman, "Some Problems in the Classification of the Upper Carboniferous Rocks of Great Britain": *Cong. de Strat. Carb.*, Heerlen, 1927–8, p. 733.

Subdivision of the Lower Westphalian should probably be made at either the base or the top of the Modiolaris Zone, where changes of fauna are known to occur; probably the base of that zone, marked by the incoming of species of *Anthracomya* of the *A. modiolaris* group, of species of *Carbonicola* of the *C. aquilina* group and of other types, will prove to be the more important. It should be noted that this line would not coincide with that taken as the base of the Middle Coal-measures, which does not appear to be marked by any important change of fauna (or indeed, of flora). In the lowest part of the Coal-measures and in the Millstone Grit the goniatite sequence will undoubtedly form the basis of a suitable classification, in which it will be possible to incorporate certain terms put forward by Mr. W. S. Bisat.

At about the horizon of the base of the Upper Westphalian, as defined above on faunal evidence, occurs a change in the flora; the Yorkian (that is, the Westphalian of Kidston) or Middle Coal-measure flora gives place to a Staffordian flora. Owing to the scarcity of exposures already referred to, there is little evidence in many coalfields as to the precise position of the boundary between the Staffordian and Yorkian. In South Wales it has been shown that the base of the Staffordian occurs not far from the base of the Phillipsii Zone, although it is not certain that they coincide.[1] In North Staffordshire, Kidston selected the base of the Upper Coal-measures as the base of his Staffordian Series, and rejected the somewhat lower horizon chosen by Wheelton Hind, who appreciated the significance of the palaeontological break referred to above, as the base of the Phillipsii Zone.[2] There does not appear to be any adequate published account of the palaeobotany of the few hundred feet of strata between the base of the Blackband Series and the base of the Phillipsii Zone, but it is quite possible that a

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[1] D. F. Davies, E. Dix, and A. E. Trueman, "Boreholes in Cwmgorse Valley": *Proc. S. Wales Inst. Eng.*, vol. xliv, 1928, p. 97.

[2] See especially the discussion on Kidston's paper (1905) referred to above.

Staffordian flora may yet be found in North Staffordshire in the lowest part of the Phillipsii Zone. In any case, the Staffordian and Radstockian together agree fairly closely in extent with the proposed Upper Westphalian, and further research may show a still closer agreement. On the other hand, it may be suggested that, so far as the Coal-measures of England and Wales are concerned, it is advisable to discontinue the use of the term Lanarkian (and perhaps as a consequence, of the term Yorkian, or Westphalian of Kidston).

On the Continent there is some confusion as to the precise meaning of the term Westphalian. By some authors (including Professor W. J. Jongmans)[1] it is limited to the equivalents of the Coal-measures, while the Millstone Grit is called Namurian. Other authors, such as P. Kukuk,[2] include the Namurian in the Westphalian, calling it the *Westphalien inférieur* and dividing the *Westphalien supérieur* into three groups. Professor P. Pruvost[3] regards the *Westphalien inférieur* as equivalent to only the lower part of the Millstone Grit of England. The uppermost division of the *Westphalien supérieur*, variously named by these authors, corresponds approximately with the division which the writer proposes to name the Upper Westphalian; as the term *Westphalien inférieur* is applied by them to only a small part of the Upper Carboniferous, it does not appear that there is much likelihood of confusion with the proposed term Lower Westphalian.

It may be noticed that a two-fold division of the Upper Carboniferous has been suggested by Mr. W. S. Bisat, who named his divisions the Lancastrian and the Staffordian.[4] Unfortunately, Mr. Bisat put the boundary of these divisions at the base of the Middle Coal-measures, where there is no important change in the non-marine fauna, and where a change in flora has yet to be demonstrated in the Coal-measures of England and Wales. At this horizon, moreover, marine faunas are infrequent and can only be used for recognizing bands and not for delimiting zones or for fixing precise boundaries to major stratigraphical divisions. In fairness to Mr. Bisat it may be noted that these main divisions are suggested to form a basis for discussion, and not with the intention that they should be universally used, but it would be distinctly unfortunate if the base of the Middle Coal-measures, already widely accepted as a stratigraphical boundary in the north of England, were given an increased importance by the adoption of this classification.

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[1] W. J. Jongmans, *Congrès de Strat. Carb.*, Heerlen, 1927–8, table facing p. 394.

[2] P. Kukuk, ibid., table facing p. 448.

[3] P. Pruvost, ibid., table facing p. 520.

[4] Perhaps it is unnecessary to comment here on Mr. Bisat's use of the term Staffordian, proposed by Kidston to replace his term Transition Coal-measures. It is very undesirable that such a term should be extended, unless the floral evidence requires it, to include on the one hand those measures which Kidston called Radstockian and on the other the Middle Coal-measures.

In conclusion, the writer suggests that the divisions based on the flora are inadequate for present purposes, but hopes that further studies of the non-marine Lamellibranchs and the various floras will afford a basis for a classification of the main part of the Upper Carboniferous. It is undesirable to attempt to construct such a classification until more precise work has been done. In view of the various classifications employed on the Continent, and especially the different uses of the term Westphalian, it will probably be necessary to introduce entirely new terms. Meanwhile, the division into the Upper and Lower Westphalian is proposed in order to emphasize the importance of the palaeontological break at the top of the Pulchra Zone.

The Zone of *Anthracomya tenuis* in the Somerset Coalfield.

By E. Dix, M.Sc., and A. E. Trueman, D.Sc.

THE paucity of animal remains in the Coal-measures of Somerset has been recognized for many years.[1] More recently Dr. H. Bolton has described fossils from various horizons in the coalfield, but his records relate chiefly to insects and marine fossils, while non-marine Lamellibranchs appear to be unusually rare at most horizons.[2] A number of species of non-marine Lamellibranchs have been recorded by various authors, but in view of the wide interpretation formerly given to the various species, many of these records cannot be used for zonal purposes.

The scarcity of non-marine shells in the area, and especially the rarity of *Carbonicola* to which Dr. Bolton has drawn attention,[3] is probably due to the conditions of deposition in the area, a similar scarcity of *Carbonicola* at certain horizons (at which it is elsewhere abundant) having been noted in parts of South Wales and in the north of France.

Recently, one of us (E. D.) has been able to secure a large collection of well-preserved shells from the roof of the Rock or Badger Seam at the Lower Writhlington Colliery. The occurrence of shells at this horizon had already been noted by Professor D. M. S. Watson and Dr. Bolton, both of whom recorded *Anthracomya phillipsii* and *A. lanceolata.*[4] Examples of the forms referred to were figured by Dr. Bolton and we are indebted to him for the opportunity of studying these and other specimens in his collection.

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[1] J. Morris, "On Organic Remains in the Somersetshire Coalfield": Geol. Mag., Vol. V, 1868, p. 356.

[2] H. Bolton, "On a Marine Fauna in the Basement Beds of the Bristol Coalfield": *Quart. Journ. Geol. Soc.*, vol. lxiii, 1907, p. 445; "Faunal Horizons in the Bristol Coalfield": ibid., vol. lxvii, 1911, p. 316.

[3] H. Bolton, op. cit., 1911, p. 327.

[4] D. M. S. Watson, "*Anthracomya* in the Radstock Coal Measures": Geol. Mag., 1906, p. 336; Bolton, op. cit., 1911, p. 323, and pl. xxvii.

The specimens from Writhlington include four main types, which we may record as *Anthracomya phillipsii* (Will.), *A. tenuis* Davies and Trueman, *A.* sp. nov., and *A.* (?) sp. nov.

The specimens of *A. phillipsii* are small but typical of the species. They usually have a strongly wrinkled periostracum.

A. tenuis is represented by numerous large and well-preserved specimens which are readily distinguished from *A. phillipsii*, and these two species do not appear to be linked at this horizon by any transitional forms. The specimens of *A. tenuis* do not show much variation and include typical examples of the species (Fig. 1, *a*, *b*). Many of the specimens have a strongly wrinkled periostracum.

Associated with these specimens and in some cases in the same shale fragment, are examples of the shells which have been referred to *A. lanceolata* Hind (a species which Bolton considered to be closely related to *A. williamsoni*). Although these shells more closely resemble *A. lanceolata* than any other described species, they do not appear to us to be identical with the holotype of that species. The horizon of the holotype is unknown and only one typical specimen from the type locality was known to Hind, but comparable forms have been collected by the writers in the *Similis-Pulchra* Zone of the north of England. The Writhlington specimens differ from *A. lanceolata* in having a longer anterior end (not less than 25 per cent of the length of the shell, as compared with 16 per cent in the holotype of *A. lanceolata*) and in the blunter form of the posterior end. They appear to represent a new species and will be described as such in due course. They are smooth shells, without the wrinkled periostracum seen in the associated specimens of *A. phillipsii* and *A. tenuis*, to which they do not seem to be

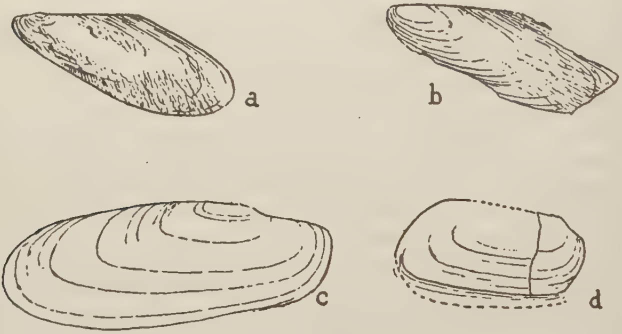

FIG. 1.—Shells from the roof of the Badger or Rock Seam at the Lower Writhlington Colliery, Somerset (now in the collection of University College, Swansea). *a*, *b*, *Anthracomya tenuis* Davies and Trueman; *c*, *A.* sp. nov. (cf. *A. lanceolata* Hind); *d*, *A.* ? sp. nov. (cf. *A. wardi* Hind *non* Salter). (All the figures are about one and a half times natural size.)

related. They represent a type of shell which is unusual in the Upper Coal-measures. A fourth species is represented in our material by a single specimen (Fig. 1, *d*); it somewhat resembles *A. wardi* Hind *non* Salter.[1]

The occurrence of typical examples of *A. tenuis* with *A. phillipsii* is regarded by us as conclusive evidence that the horizon of these measures is equivalent to the zone of *Anthracomya tenuis* in South Wales, but until further evidence is available it remains uncertain what part of the zone is represented. The absence of records in South Wales of the new species of *Anthracomya* may possibly indicate that the Writhlington horizon is higher than the Wernfraith Seam.[2] It may be noted that Dr. R. Crookall has made a study of the flora at Writhlington and regards these measures (a part of the Farrington Series) as equivalent to the lowest group of the Radstockian,[3] a conclusion which would be in accord with their reference to the zone of *A. tenuis*.

In other parts of the Somerset coalfield the distribution of marine bands and the scattered records of *Carbonicola* and *Naiadites* suggest that further investigation may reveal a sequence in Somerset which will agree in many features with that of South Wales.[4]

Some Characteristic Structural Types in Eastern Asia and their Bearing upon the Problem of Continental Movements.

By J. S. Lee.

(*Concluded from p. 473.*)

LASTLY a reference must be made to the nu-delta structures which characterize the contact zone between the continent of Eastern Asia and the floor of the Pacific. In the Sakhalin-Yezo-Kuriles system we find, by experiment, that the northern part of the system was pressed towards the continent to a greater extent than the southern part of it. This is a consequence to be naturally expected. In the Kuriles we find a succession of fractures which prove, beyond any doubt, that the region to the west of those lines effected a southerly or south-westerly horizontal shear against the Pacific. Such a movement not being parallel to the continental border, would necessarily arouse a lateral compression between the continent and the ocean base. Now since the southern terminus of the triangular area covered by the system lies against the Inshan zone which behaved as a strengthening rib on the part of the continental mass against lateral pressure, it would be extremely difficult for the southern apex of the triangular area to shift westward. On the other hand the northern part of the area does not encounter such extraordinary resistance. Consequently the whole area suffers a counter-clockwise twisting movement with the result that the nu-delta system was generated. In this way we are able to understand how the Sakhalin-Yezo-Kuriles system was produced through a southward movement of Eastern Asia.

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[1] Wheelton Hind, "A Monograph on *Carbonicola, Anthracomya,* and *Naiadites*": *Pal. Soc.*, 1895, p. 105.

[2] J. H. Davies and A. E. Trueman, "A Revision of the Non-Marine Lamellibranchs of the Coal Measures, etc.": *Quart. Journ. Geol. Soc.*, vol. lxxxiii, 1927, p. 245.

[3] R. Crookall, "On the Fossil Flora of the Bristol and Somerset Coalfield": Geol. Mag., Vol. LXII, 1925, p. 398.

[4] *Anthracomya phillipsii* was recorded by Messrs. T. C. Cantrill and J. Pringle at a depth of between 580 and 600 feet in a boring at Hemington, Somerset (*Summary of Progress of Geol. Surv.*, 1913–14, pp. 100–1). Dr. F. L. Kitchin has kindly allowed us to examine the specimens referred to, which are in the collection of the Geological Survey (Pl. 1673). The material is badly preserved; it includes *A.* cf. *phillipsii* but we are not able to recognize *A. tenuis* or any other species.

The same argument applies to some extent to the Formosa-Borneo-Marianne system; for it is also quite obvious that the region to the west of Borneo cannot afford much space for its westward displacement because of the presence of the Indian Ocean on the west and because of the narrowness of the pliable continental mass that stretches between Borneo and the south-western border of Sumatra. In addition to these circumstances there is the effect of a clockwise torsional shear, for which evidence is afforded by the pronouncedly arcuate shape of the two arms of the system. This latter effect is in harmony with the evidence independently furnished by the nu and eta systems. The reason that the configuration and structure of southern Borneo differ from those of Yezo is obviously to be found in the presence of the Java mass which by virtue of its lambda structure, must have been subjected to a N.-S. compression as well as a clockwise torsional shear.

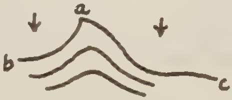

Fig. 8.—Geniculum type of structure. *a*, apex; *ab* and *ac*, wings; arrows indicate directions of principal movements.

Now if we synthesize all those processes of tectonic movement, we are forced to the conclusion that not only do the several concurrent processes fall into harmony with one another, but they are distributed in a definite order. Apart from the E.-W. zonal disturbances, we see that all the independent classes of tectonic evidence join to show that the several latitudinal sections of Eastern Asia have all moved southward against the Indo-Tibetan massif on the west and the Pacific floor on the east, and that the southern part of Eastern Asia has at the same time accomplished a clockwise twisting movement against the East Indian Ocean and around the Tibetan massif. It is the effect of this twisting movement that has given rise to a deceptive appearance in the arrangement of Sumatra and the Sunda Islands, so that south-eastern Asia looks as if it has migrated extensively to the west. If the evidence produced here is of any value, the exponents of the hypothesis of continental migration must at least withdraw their claim from this part of the world.

We must however admit that the continental mass of south-eastern Asia has been differentially driven to the west against Tibet, Himalaya and India to the extent that is afforded by the meridional folding in south-western China, Burma, Indo-China, etc. Since the available evidence goes to show that the Indo-Tibetan massif has remained as a gigantic rigid block and has allowed a relatively small amount of parallel shear in the region to the immediate east of it, Eastern Asia would be necessarily given a greater tendency to accomplish a southerly shearing movement in its eastern part as well as to glide along the contact plane between the continent and the Pacific floor. The fact that folds of Sinoid type are far more predominant in the eastern and southern parts of China than the north-westerly folds in the south-western part of the country completely bears out the first part of this inference. As to the gliding effect along the Pacific border, evidence is furnished by the compact lines of *en échelon* fractures as well as the volcanic activity so rampant from the Kuriles down to the Pelew Islands. This being so, Eastern Asia, or at least the southern part of it, would be left no other way but to rotate around the Tibetan massif. Such a rotating movement may have been enhanced by the very nature of operating force which will be discussed presently.

Summarizing the results obtained from Eastern Asia, it may be said that the several inferred processes of movements in the same region entirely fall into harmony with one another. Having thus gained some confidence in this method, we will now proceed to apply it to other continental areas. Detailed discussion is however admissible neither by space nor by the writer's limited knowledge. Nevertheless, certain broad features stand out in striking relief as we view them in the light thrown by this method.

Whatever types of structures may occur in Australia, its surrounding island festoons and its structural relation with the deep-reentrant Banda Arcs and Timor and Rotti, demonstrate that that vast area is covered by an eta system as already discussed. This means that Australia as a whole has undergone a clockwise twisting movement with its axis of rotation placed somewhere in the Banda Sea. Such a twisting movement is precisely the kind of process required to produce the inverted lambda structure embodying the Australasian festoons and the islands of Tonga, Kermadec, New Zealand. The presence of the Tonga Ridge and

New Zealand would seem to suggest, according to the mechanism involved in producing the lambda structure, that herein we find the actual border of the Pacific. This agrees well with the andesitic line of demarcation.

In Western Australia there is an extensive E.–W. zone of folding stretching from the headwater of the Gascoyne to the north-western end of Lake Carnegie. Within this relatively narrow structural zone steeply folded beds of conglomerates, sandstones, quartzites and phyllites are almost continuously exposed. These Mosquito Creek Beds, probably of pre-Cambrian age, are not the only ones involved in the E.–W. folding; their overlying series, namely, the Nullagine Beds, seem to have been also affected, though to a lesser degree; for they, too, exhibit an east and west strike, and in places dip as much as 40° as the zone is approached.[1] The most accentuated belt of this zone is located in between 25° and 26° or 25° 30′ on the average—a position curiously corresponding to that of the Nanling Range in the Northern Hemisphere. It would not be surprising if future investigation shows that the Warburton and the Musgrave Ranges form a part of this east and west zone.

To the south or rather south-west of the above-mentioned structural zone, the country is largely occupied by granite with numerous dykes and mineral lodes running generally in a north-westerly or north-north-westerly direction. To the north of the east and west zone, there is an extensive stretch of relatively flat Nullagine Beds followed northward by old granites, greenstones and Palaeozoic formations which latter are generally impressed with a north-easterly strike as for instance in Eastern Kimberley District. It would thus seem that the whole area of Western Australia is covered by an epsilon with its axis coinciding with the east and west zone and its apex located somewhere in the lower part of the Gascoyne Valley or in Sharks Bay. Should this epsilon system be eventually established, it would mean that prior to the rotational movement, Australia had sheared westward. The fact that the Mosquito Creek Beds do not strike exactly east and west but rather west by north in the above-mentioned zone, tends to favour the inference that the east and west zone had been slightly displaced after its formation through the clockwise rotational movement of the whole continent since late Mesozoic time.

An epsilon structure of gigantic scale covers an immense area of Eurasia. The wings of this system start from the Rhine Graben in Europe and extends to the valley of the Yenissei in Asia. The Ural represents its axis. The development of this system proves that that part of Eurasia which is embraced in this system has moved to the south against the Indo-Tibetan massif on the one hand and southern Europe, Africa, and Arabia on the other. The reason that its apex is located in the longitude of the Ural or on the northern coast of the Arabian Sea is probably to be traced to an inherent weakness in Lemuria or that part of the Gondwanaland which connected India and Africa. It seems then that the existence of the great Eurasian epsilon system does not only afford positive evidence for a southward movement of Eurasia, but argues for the breaking down of a once existing land-bridge between Africa and India.

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[1] H. W. B. Talbot, "The Geology and Mineral Resources of the North-West, Central and Eastern Divisions," *Geol. Surv. Western Australia*, Bull. No. 83, pp. 59–63, 71–73, 81, 82, 137, (1920) Maps and Sections, 1928; ibid., No. 87, pp. 15–18, 1926.

Because of the fact that Europe has undergone a series of tectonic metamorphoses through fragmentation or otherwise since the Caledonian movement, it is extremely difficult to decipher the several structural types among the superimposed tectonic elements of different origin. Nevertheless, certain predominant features can be recognized.

In western Europe, namely, the region to the west of the longitude of the Rhine Graben, two more epsilon systems of moderate size occur ; the one in England and the other in France. In England the axis of the epsilon system is represented by the Pennine Range which rose out of the desiccating Permian Sea. The presence of its western wing is indicated by the strips of outcrops of the Carboniferous Limestone and Millstone Grit in Flint and Denbigh. The extension of the western wing closely follows the north-eastern border of the Welsh mass which had already been profoundly impressed with the Caledonian strike and was therefore no longer adaptable to cross folding. The eastern wing has been largely denuded away, and covered by younger deposits. The configuration of the two wings is however still recognizable from the horseshoe-like extension of the Triassic plain which spreads out from Chester to Stafford, Worcester, Warwick, and then sweeps round to Leicester, Nottingham, and the eastern part of Yorkshire. With a limited knowledge of British geology the writer is not in a position to say where the denuded and buried eastern wing of the system should exactly lie ; but he is more or less convinced that such a feature must exist under the younger deposits, and that its axis cannot be located further south than a line drawn from Warwick to the mouth of the Welland. It is further believed that an exhaustive search along these lines may throw some light on the underground distribution of the coalfields of the Midlands.

In France the ancient rocks of Brittany show a dominant north-westerly strike. On the other hand, a north-easterly strike is widely observed in eastern France. Between these two sets of strikes there rises the Massif Central. The latter corresponds to the axis of the epsilon system, and the two sets of strikes named to the wings. As there are reasons to believe that France has persisted as a tectonic unit since the Palaeozoic Era, the difference in age of the movements which affected the different parts of the system does not constitute a serious objection to regarding them as members of one system.

The Alps, Apennines, Dinarides and Carpathians are features attached to the great Eurasian Epsilon system and at the same time form an eta system of their own. They have therefore encountered an enormous N.–S. compression, and been subjected *pari passu* to a clockwise torsional movement with the axial region probably located somewhere in the Gulf of Genoa or the Ligurian Sea.

The Caledonian system of folding forms a group of independent features. The genesis of this ancient system cannot be readily explained from its fragmentary remains. It is highly probable that parts of N.–W. Europe have broken down since Palaeozoic time. It would not be surprising if gravitational measurements should recover fragments of the lost continent in the North Atlantic. At all events, there seems to be no immediate necessity to pull Newfoundland eastward through a vast space so as to fit on to Ireland.[1]

Leaving the Caledonian system aside, we may ascribe the broader structural features of Europe to three groups. Firstly there are the Variskian or Hercynian and the Pyrenees Ranges. These belong to the west and east zones of disturbance corresponding to the Tannu-Kentei and Inshan, somewhat modified through the influence of the great Eurasian epsilon system. Consequently these zones are slightly turned to the north as they extend westward. We see, in fact, that the eastern part of the Variskian is closely set against the northern border of the Bohemian massif ; fragments of its western part appear in south-western England and Ireland. Similarly, the main axis of the Pyrenees does not strike strictly E.–W., but north of west. These zonal disturbances were apparently brought about by longitudinal compression.

The second group comprises the epsilons of England and France. They both demonstrate a southward shear of the regions involved during, at least, the Hercynian revolution, for the apices of the epsilons point to the south. The first of these epsilons seems to have become stabilized since the British Isles severed their tectonic relation with Fennoscandia, and the second became likewise stabilized since the development of the Rhine Graben.

The third group embraces the noble mountains of south-eastern Europe, probably including the Jura Mountains. These, as already shown, indicate a twisting movement as well as a N.–S. compression. We may therefore conclude that western Europe as a whole moved southward, while south-eastern Europe accomplished a clockwise rotation and at the same time suffered a N.–S. compression.

Out of the fragmentary information from Africa, very little can be gathered concerning the processes of crustal movements in that continent. What we do know for certain is the existence of two zones of powerful orogeny and one zone of tafrogeny. The first zone of powerful orogeny embodies the Atlas Ranges. As has been shown, the Atlas Ranges probably embrace two distinct units. The northern one comprises the Little Atlas and probably the Betic Cordillera on the southern Spanish coast, these being distinguished from the rest of the Atlases by their essentially E.–W. trend. The southern limit of this E.–W. zone is located on the average in about 35° N. The southern unit comprises the Middle Atlas, the Great Atlas and the Saharan Atlas, all having a S.–W. trend. These seem to constitute an xi type of structure originating probably from a relative westward movement of North Africa against the European mass or vice versâ.

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[1] C. Schuchert, " Hypothesis of Continental Displacement," in *The Theory of Continental Drift*, 1928, pp. 129–133.

The second zone of orogeny is found in the Cape Fold Ranges. Apart from their western terminus, these mountains are almost exactly east and west in trend, and are singularly located in the neighbourhood of 34° S., that is, they are located in a latitudinal position not incomparable with the average position of the Little Atlas and the Tsinling in the Northern Hemisphere. In this connection it may be mentioned that there still exists a minor east and west zone of disturbance to the north of Johannesburg,[1] bringing up the Igneous Complex of the Bushveld as well as the Witwatersrand System. This zone is some 240 miles long from the west to the east being located between the latitudes of 25° and 26° S.—a position corresponding to that of the Nanling in Eastern Asia. Are these concurrent facts a mere coincidence ?

These E.–W. zones were undoubtedly produced through longitudinal compression which at the same time explains the genesis of the zone of tafrogeny, provided it be assumed that the whole of the African Continent has been subjected to a more or less uniform N.–S. compression. As a result of an intense N.–S. compression more or less *evenly* applied to the whole block, E.–W. tension would be unavoidably called into play. Thus the Rift Valleys of East Africa might be primarily produced. Indeed the breaking down of Gondwanaland may be explained in the same way.

From the tectonic map of western Africa constructed by Lemoine [2] it appears not improbable that an epsilon system exists to the west of the central massif of the Sahara. The axis of the system probably runs from O. el Abid towards the direction of Monrovia. In the Kong area Lemoine marks a slightly bent structural zone which he designates the " Zone des petits massifs " extending N.N.E. up to the vicinity of Timbuctoo. This line of structure probably represents the eastern wing of the system. The western wing is not seen, having probably sunk into the Atlantic. If this interpretation proves to be acceptable, it will mean that western Africa has also undergone a southward movement in some ancient geological time, and that the ancient African Continent extended further west than its present boundary.

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[1] F. H. Hatch and G. S. Corstorphine, *The Geology of South Africa*, pp. 118–23, fig. 25, and maps.

[2] P. Lemoine, " Afrique Occidentale," *Handb. Reg. Geol.*, 14 Helt, p. 57, fig. 13.

It is worthy of note that in the same work of Lemoine, he reproduces a tectonic map due to C. B. M. Flamand.[1] On that sketch map an assemblage of tectonic types, including the nu, xi, and other syntaxial forms, is indicated. The nu type as developed in the Ugarta Chain has its anterior end pointing to the south. A local clockwise rotation against the Gurara massif, or a counter-clockwise rotation on the part of the latter massif, would thus seem to have taken place in Hercynian time.

The structure of North America furnishes remarkable examples of tectonic types. The whole of that continent may be regarded as a great epsilon system which has its western wing in the Cordilleras and eastern wing in the Appalachian Mountains. A broad belt of central swell, or the " backbone " of North America of A. Keith, represents its axis.[2] The United States Mountains which rose out of the Franklinian Geosyncline probably form the eastern wing of another epsilon system, homologous to the great epsilon and comparable with the eastern part of the Amphitheatre of Irkutsk. The axis of this inner epsilon is presumably located somewhere in the drowned old land of Pearya. It is true that the orogenic phase of movement did not take place simultaneously in the two wings of the great epsilon, but the succession of events generally lagged behind in the Cordilleras. This fact opens up the problem—an extremely important one—of the necessary sequence of the different phases of tectonic movements in a given structural zone, say from a " mobile " geosyncline to " stable " blocks, and the migration of orogenic belts. There is a mass of facts which contribute to the solution of this problem, but unfortunately they cannot be dealt with here. For the present purpose it suffices for us to note that at the end of Pennsylvanian time, when violent movement took place in the Appalachian area, a broad folding must have also affected the region of the Cordilleras; for otherwise, the Palaeo-Cordilleran Geosyncline would not be able to reappear after its apparent disappearance in early Pennsylvanian time, and the " Ancestral Rockies " of Schuchert would not have been formed. The latter feature demonstrates with striking lucidity the existence of an axis in the great epsilon system.[3] Conversely, when the Cordilleras were uplifted at the end of the Cretaceous, the Appalachian area appears to have undergone no appreciable deformation, though granitic intrusion may have taken place along the Atlantic coast. This anomaly is to be traced to a distinctive cause which is made plain by investigating the structural types of the Cordilleras and the tectonic ranges of Central America.

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[1] P. Lemoine, op. cit., p. 55, fig. 10, 1913.

[2] A. Keith, " Structural Symmetry in North America," Presidential Address to the Geological Society of America, *Bull. Geol Soc. America*, vol. xxxix, pp. 321–86, 1928.

[3] C. Schuchert, " Sites and Nature of the North American Geosynclines," *Bull. Geol. Soc. America*, vol. xxxiv, pp. 151–230, maps 11, 12, 1923.

The Cordilleras of North America form an eta system on a gigantic scale. The cranium of the system lies in southern Alaska, being characterized by the fold-arcs of the Kenai-Chugach-St. Elias and Alaska-Mentasta-Nuzotin Ranges. Crowning arcs are developed along the course of the Yukon and further north in the Endicott Range. The Cordilleras of British Columbia and western United States form its limb. Within the limb of this system structures of the reversed lambda type are sometimes developed, e.g. along the coastal region to the north of Vancouver Island. These structural types show that North America as a whole must have undergone a clockwise torsional movement with the axial region located somewhere in the Gulf of Alaska. It is because of this twisting movement that the pressure against the eastern border of the continent is largely compensated.

To these dominant zones we must add two minor zones of E.–W. trend, which are nevertheless significant. The one is the Ouachita Mountains of Arkansas and Oklahoma, and the other is the Sonoran Geosyncline. As to the tectonic features of the Sonoran Geosyncline the writer has so far failed to gather any information, but in the Ouachita Mountains the rocks are definitely known to have been overthrust to the north. The remarkable point about this essentially E.–W. zone of powerful compression is that it lies approximately between 34° and 35° N., that is, its latitudinal position corresponds to the average trend of the Atlas and the Tsinling in the northern hemisphere and that of the Cape Ranges in the southern hemisphere. Might this again be attributed to mere coincidence ?

We are thus led to conclude that North America as a whole has moved southward and at the same time undergone a clockwise rotational movement against the Pacific floor with the Gulf of Alaska as its centre of rotation. As this process is relatively simple, appeal can be made to our paper experiment. The experimental result seems to be on the whole satisfactory (Pl. XVII, Figs. 5, 6).

In Central America structures of the reversed lambda type occur in Chiapas, Guatemala and Honduras. The dominant limb of the system extends along the Pacific coast, marked by violent igneous activities. In the Great and Lesser Antilles structures of different types are superimposed. The first thing to be noticed is an E.–W. zone which extends from Jamaica to the southern part of San Domingo, Porto Rico and the Virgin Islands. This zone lies between latitudes 18° and 19° N. There is then about 16° interval between this zone and the Ouachita Mountains—exactly double the number of the 8 degrees interval found elsewhere. The western portion of this zone is syntaxially connected with the axis of Cuba so as to form a pseudo-reversed-lambda type. These syntaxial lines are regarded as a pseudo-reversed-lambda type because the subordinate limb describes no appreciable bending. If we may judge from the result of our experiment (Pl. XVII, Figs. 5, 6) it appears that the formation of the Antilles is in part due to the resistance offered by the Caribbean area which did not follow the torsional movement of North America, but stayed behind. The eastern end of the E.–W. zone merges into an eta system which has its cranium in the acute arc of the Lesser Antilles and its limb in the Caraibe Chain and the Coro Mountains. The structural axes in these mountains are arranged after the xi type[1] which characterizes the limb of the eta system. The area covered by the Caribbean Sea underwent a local torsional movement, clockwise, with the axis of rotation lying somewhere inside the Lesser Antillean Arc.

South America may be divided tectonically into two parts. The northern part covers that portion of the continent which is bounded on the west by a bulging front extending from Coro to the southern extremity of Peru. All along that front facing the Pacific, the Andean Chain describes a sweeping arc with its tectonic trend approximately following the coast-line. The arc represents the two wings of an epsilon system. The apex of the system lies in the Gulf of Guayaquil. The Amazon seems to flow exactly along the axis of the epsilon. On both sides of the Amazon Valley the rocks appear to strike, according to H. Keidel,[2] east and west. The axial zone would then seem to extend for a considerable width which is not unnatural when we consider the size of the whole system. The northern wing merges into the eta system of the Lesser Antilles and the Coro Mountains. The southern wing appears to have terminated more or less abruptly against the southern tectonic unit. The presence of this Andean-Amazon Epsilon indicates that the region covered by the Amazon Basin moved westward against the Pacific and the Caribbean Sea.

The southern part of the continent is characterized by the reversed lambda type of structure with the mighty Andes forming its dominant limb. Numerous minor structural lines, slightly convex to the south-west, stream towards the Pacific coast from inland. The principal group of these lines extends obliquely across the continent, and traverses the region of Buenos Aires. All these constitute the subordinate limb of the system. On the southern tip of the continent, a nu type of structure seems to have developed traversing Tierra del Fuego with its anterior end pointing to the N.W. These two types of structure join to show that the southern part of South America has undergone a clockwise twisting movement against the Pacific on the one hand and the Atlantic or Poseidon on the other. The development of the Franklinian Geosyncline and its associated features is probably also due to this type of movement.

In this rapid survey of the facial features of the world, it will be noticed that the highly deformed tracts are located in the continental areas and particularly on the borders of the continents. Of course we do not know what features are developed on the ocean floor, except for the fragmentary indications derived from those volcanic islands that rise above the surface of the water and from sporadic soundings, One thing however seems to be quite certain; that the true ocean base behaves as a rigid block against which the continents moved in all sorts of ways. The ocean deeps and submarine ridges are, with the exception of the Mid-Atlantic Ridge, largely associated with the bordering zones of deformation of the continents. The reason for this remarkable difference in the mechanical behaviour of the continents and the oceanic base must be traced either to the nature of the force which promotes earth movements or to the superior strength of the ocean base, or both.

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[1] E. Suess, op. cit., tome iii, p. 1295, fig. 292.

[2] H. Keidel, "Über das Alter, die Verbreitung und die gegenseitigen Beziehungen der verschiedenen tektonischen Strukturen in den Argentinischen Gebirgen," *Cong. Géol. Int. XII^e Session*, pp. 671–87, fig. 1, 1913.

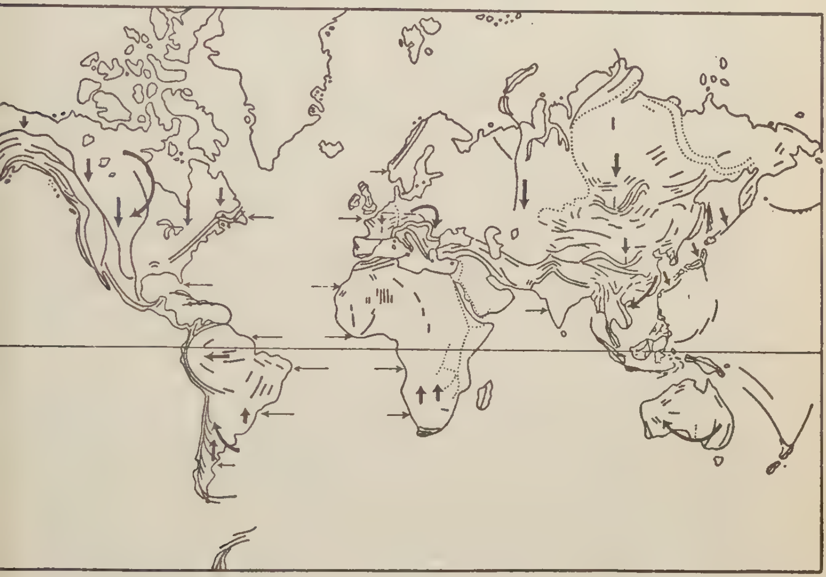

Fig. 9.—A diagrammatic representation of some principal structural types of the world developed in the course of geological time and the principal movements of the upper layer of the continents. Continuous lines: folds or thrusts; dotted lines: faults or rifts. Thick arrows indicate directions of movements deduced from the structural types; thin arrows indicate directions of hypothetical movements of continents with reference to the mid-Atlantic Ridge.

With the nature of the force we shall deal presently. Of the relative strength or rather relative stability of the continent and the oceanic base some light can be gained by considering the subterranean thermal condition and its bearing upon the relative strength of the successive levels below the surface. There is little doubt that mobility of rocks increases with the increase of temperature.[1] On the other hand, pressure tends to increase their strength.[2] Within the upper layer of the earth-crust we may assume that pressure increases linearly with depth, but the theory of a cooling earth implies that temperature increases with an increasing gradient as we go deep down. Thus a zone of minimum strength would occur at some definite depth, which depends largely upon the radioactive content of the layer and the physical properties of the bed-rock. Assuming exponential distribution of radioactive matter and lower radioactive content in rocks forming the oceanic base, H. Jeffreys [3] shows that in the continent the cooling at a depth of 370 km. " since solidification " is 162°, whereas at the same depth below the ocean floor it amounts to 180°. Although more substantial data are required to establish these figures, there seems little doubt that the region below the ocean is cooled to a greater extent than that under the continental surface.

This, together with the average higher altitude of the continents would place the zone of minimum strength at a higher level in the continental mass. Along the border-land between the continent and the oceanic base, the zone of minimum strength would be inflected. Thus weakness is induced along the continental border, which will be naturally predisposed to deformation due to lateral pressure.

Because of the presence of a zone of minimum strength at a higher level in the continents and because of the tendency, on the part of granitoid rocks, to develop plasticity even below their melting point, the movement of the continents does not necessarily involve the whole thickness of the continental mass, the sial, but most probably has been brought about by shear at successive levels. In this way we can easily account for the development of extensive thrust without involving the displacement of the site of the continents. Those parts of the continent which are shorn of their upper layers might be compensated by isostatic rise of the lower strata. It is indeed not impossible that the strata which are now locked in the Himalayan folds might have originally covered a part of the Tibetan Plateau. The various horizontal shearing movements which we have seen in different parts of the continents are then probably accompanied by vertical shear at successive depths. The principal plane of vertical shear possibly falls in a zone of minimum strength which may correspond to the zone of flow of Van Hise.

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[1] F. D. Adams and E. G. Coker, " An Experimental Investigation into the Flow of Rocks," *Am. Journ. Sci.*, Fourth Ser., vol. xxix, no. 174, pp. 481–5, 1910.

[2] F. D. Adams and L. V. King, " An Experimental Contribution to the Question of Depth of the Zone of Flow in the Earth's Crust," *Journ. Geol.*, vol. xx, no. 2, p. 97 et seq., 1912. F. D. Adams and J. A. Bancroft, " On the Amount of Internal Friction Developed in Rocks during Deformation, etc.," ibid., vol. xxv, no. 7, p. 597, et seq., 1917.

[3] H. Jeffreys, *The Earth, its Origin, History and Physical Constitution*, pp. 87–91, 1926.

So far, we have confined our attention to movements connected with direct compression or shear. There still remains a category of important tectonic features which are usually attributed to tension, namely faults and rifts. It was noted at the outset that this class of features cannot be produced with satisfaction by such experimental methods as we have used here. We can therefore only make a few broad remarks on their genesis from a theoretical point of view.

There are two kinds of normal faults which must be clearly distinguished from each other. The one may be genetically termed cross faults, running more or less perpendicular to the axes of the xi folds which they cross. Classical examples of this type are found in the western Harz and in the neighbourhood of Coblenz.[1] This kind of fault generally results from shear; for an analysis of shearing stress shows that it is to be resolved into tension and compression at 45° to the direction of shear and at right angles to each other. In a region which has suffered a powerful shear we may therefore expect to find folds of the xi type in one direction, about 45° to the direction of shear, and a group of parallel faults perpendicular to the folds. They must be, in general, developed simultaneously. If, however, the shearing movement be not very intense, folding is usually the dominant phenomenon. On the other hand, if the region that suffers the shearing movement has already become stabilized to the extent that it is no longer capable of yielding by folding, then faulting would be the only visible result.

The other kind of normal fault may be genetically termed a sequent fault. Sequent faults generally follow the strike of the folds which they accompany. Their genesis is closely associated with, but subsequent to, the process of folding. Their origin is rather to be attributed to the relaxation or cessation of pressure combined with the effective operation of gravity, than to tension. Numerous sequent faults occur in South-eastern China in association with the Sinoid folds, and follow the same north-easterly strike.

Unquestionable tensional fracture is evidenced by rifts. The tensile stress may be developed through a powerful compression more or less evenly applied in the direction perpendicular to the direction of the tensile stress, or may simply be due to the pulling asunder of two adjacent tectonic units. The latter is exemplified by the development of the Yenissei Fault; for, as we have already seen, the region to the east of the Yenissei Valley moved southward against the Indo-Tibetan block, and that to the west of that line also moved southward against the same block. There will be left no alternative for the boundary between the two units but to be pulled asunder to the north of the resistant block. This independent evidence afforded by the Yenissei Fault thus corroborates our conclusions already reached from the study of the tectonic types of Eurasia.

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[1] H. Quiring, *Jahrb. Preuss. Geol. Landesanst.*, Bd. xlix, part 1, pl. 8, 1928.

In the development of the Rift Valleys of East Africa and the Great Valley of South Australia, the two processes probably took place simultaneously. That is, these two continental masses were subjected to a powerful longitudinal compression and at the same time to an east and west tension due to vertical shear. The longitudinal compression is undoubtedly to be traced to their tendency to shift towards the equator. The cause of the vertical shear will be considered later when we come to deal with the nature of the force that promotes tectonic movement at large.

The most remarkable of the three types of fractures just referred to is the sequent fault. Since this type of fault indicates the relaxation or cessation of pressure, we must understand that the various shearing and compressional movements already discussed did not proceed continuously but periods of quiescence intervened. And further, since sequent faulting generally immediately follows compression and shear, enquiry must be made into the circumstances or causes which led to the temporary removal of the force. If we recapitulate the results so far reached, they will reduce the imaginable causes to a possible few.

VI. Conclusion.

The more important results that we have obtained in the foregoing discussion may be summarized as follows :—

(1) Powerful orogenic movements are largely restricted to continental areas, particularly along their borders. The oceanic floor, especially the Pacific, behaves as a resisting block.

(2) Parts of the continental areas are subjected to east and west zonal disturbance probably controlled by zonal harmonics of some higher order. The successive zones are separated by an interval of about 8° of latitude or its multiple.

(3) Eastern Asia as a whole shows a tendency to have moved southward against the Pacific on the one side and Indo-Tibetan massif on the other. At the same time it tends to rotate clockwise around Tibet. The effect of this rotating or twisting movement becomes more pronounced towards the southern part of Eastern Asia. The equatorial belt has, however, not followed the twisting movement, but remained behind.

(4) Australasia also shows a tendency to have rotated clockwise, with its axis of rotation located somewhere in the Banda Sea. Prior to, or contemporaneous with, this rotation the western plateau of this land-mass may have been subjected to a north–south compression as well as a slight westward movement.

(5) Eurasia, as delimited by the Yenissei Fault on the east and Rhine Graben on the west, has moved, as a whole, southward against the Indo-Tibetan massif on the one hand and Africa-Arabia on the other.

(6) Western Europe probably moved southward through lateral shear during the Armorican Movement, but *en bloc* since the development of the Rhine Graben; whereas south-eastern Europe exhibits a tendency to have rotated clockwise, with its axis of rotation probably located in the Ligurian Sea.

(7) Africa as a whole has been subjected to a powerful longitudinal compression as well as an east and west tension.

(8) North America has moved southward and at the same time rotated clockwise with its axis of rotation located somewhere in the Gulf of Alaska. The area covered by the West Indian Archipelago has not however followed the rotational movement, but remained behind.

(9) The northern part of South America, namely the area covered by the Amazon Basin, appears to have shifted westward; the southern part of the continent has scored a very powerful turning, clockwise, encountering a mighty resistance from the Pacific all along its western front and a somewhat alleviated resistance from the Atlantic in its north-eastern part.

(10) The movements specified above probably do not involve the entire thickness of the continental mass, the sial, but are accomplished by shear along some horizontal plane or successive shear along horizontal planes not very far removed from the surface. The principal plane of shear probably falls in the zone of flow.

(11) The shearing and compressive movements are episodic. They are often immediately followed by relaxation or cessation of pressure.

(12) In regions where the tectonic units are not deranged or destroyed in the course of time, movements with the same general tendency often recur. This points to the same source of force that gives rise to the successive movements.

There seems no force of one and the same origin that can comply with all these conditions other than that due to change of the earth's rotational speed. If the rotational speed of the earth has remained constant throughout the long span of geological time, the figure of the earth would have long ago established its equilibrium so that the resultant of gravity and the rotational force would be just normal to the surface of the earth at any point. If, however, the rotational speed be increased after the equilibrium figure has been established, then the whole earth will be compelled to adapt a new figure in order to reach an equilibrium under altered conditions.

The harmonic deformations that we have actually observed in parts of the continental areas are an eloquent indication that the earth has indeed made such attempts. A thorough treatment of this type of deformation may throw some light on the internal constitution of our planet. The problem is however exceedingly delicate, and must be left to the competent hands of geophysicists. Fortunately other groups of evidence are available. They do not lead us to an inextricable position shrouded in the darkness of the earth's interior, but equally well show the nature of the same operating force.

If the increase of speed originates from the barysphere, then in view of the probable presence of a zone of minimum strength at a certain depth below the earth's surface, the rock masses lying above that zone would tend to remain behind when its strength or cohesion is exceeded; in other words, they would, in that extreme case, tend to move westward with reference to the surface of the barysphere. Had the earth been clothed with a perfectly rigid and uniform shell, such an effect would be hardly noticeable on its surface. But the facts are otherwise. We ought then to find some longitudinal zones of compression along the western border of those tracts which are least competent to keep pace with the rotation of the underlying barysphere, and longitudinal zones of tension along the western border of those tracts which are ready to take up the increased velocity of the barysphere. It is exceedingly difficult to deduce on theoretical ground as to where exactly these zones should lie; for the factors involved are so numerous and they vary so widely under local and regional circumstances. There are however four fundamental points which largely determine the issue. Firstly, for a given increase of angular velocity the increment of surface linear velocity increases towards lower latitudes, and reaches a maximum on the equator. Secondly, the momentum to be transmitted per unit area through the sub-zones of the upper stratum of the continent is proportional to the linear velocity of its subsurface and the total mass to be pulled eastward. Thirdly, the efficiency of transmission of the momentum depends upon the physical or mechanical properties of the layers through which it is to be transmitted. Fourthly, the negative momentum gained by the upper stratum of the continent depends, in part, upon its vertical as well as horizontal distribution and its initial structure.

From these considerations it appears that for those continental masses which possess sub-zones of similar mechanical properties, the larger ones that are in low latitudes or in the equatorial belt and rise to a relatively greater altitude would have a greater tendency to shear westward; whereas smaller masses with an extensive base would be more readily carried forward. An example of the former type of land-mass is found in the northern part of South America where the Andean-Amazon epsilon shows a prominent westward movement. If the N.–S. structural planes in the Central Massif of North Africa be proved to be due to a vertical shear to the west and if the epsilon of West Australia be established, then these masses afford us further examples to the same effect. As regards the lesser masses with broad bases, the East and West Indian Islands may be taken as examples. In none of these islands do we find any reliable evidence for a relative westward movement to a notable degree. On the contrary, they exhibit a strong tendency to remain in their original positions on the barysphere.

The Antarctic Continent affords some evidence of interest for differential rotation. The whole of that continent may be regarded as a rotating disc co-axially attached to the barysphere. When the sub-zones of that continent fail to transmit the increased speed to their superior layers, the latter will tend to rotate backward—westward—with reference to the barysphere. This effect ought then to be tectonically expressed somewhere on the continent. The reversed lambda or convergent xi types of structures developed in Graham Land seem to fulfil our expectation.

The most important zone of compression due to differential rotation between the upper layers of the earth's crust and the barysphere is undoubtedly the Cordilleras of the Americas, and the most important zone of tension due to the same effect is the Rift Valleys of East Africa. Of the factors which determine the respective positions of these zones, regional variation of the physico-chemical nature of the sub-zones of the supercrust is probably among the most important. It is a common laboratory experience that an addition of alkalinity to a mixture of mineral substance often means a lowering of its fusion point or an increase of mobility. If the sub-zones of the Atlantic Province be endowed with higher alkalinity towards its western part, in other words, if the alkalinity of the sub-zone of the supercrust decreases from Eurafrica towards Eastern Asia, or more broadly, towards the eastern part of the Pacific Province, then, it is to be expected that Asia would be more readily pulled eastward, while Eurafrica would be less and the Americas would be still less adapted to keep pace with the accelerated rotation of the barysphere; and consequently the more westerly of these lands would show an increasing tendency to be left behind. Here we have raised the whole problem of petrographical provinces, the relative strength or viscosity between the alkaline and sub-alkaline rock-types, etc. The subject requires a thorough investigation which cannot be undertaken for the present.

The absence of the Cordilleran type of mountains along the present western border of the Eurafrican continent need not be regarded as an objection to our argument. As far as our present knowledge goes, we have no means of ascertaining what portion of the Caledonian mountains may have sunk into the Atlantic through drawing out and consequently thinning down of their sub-crustal part; nor have we sufficient data to determine the composition and structure of the whole of the Atlantic floor. It is a matter of unusual interest that materials brought up by volcanic eruptions in the Atlantic sometimes contain the continental type of rocks. If the nature of the sub-zones of the Atlantic floor be such that the revolving movement of the Atlantic floor could keep pace with that of Eurafrica under changed rotation, there would be no relative movement along the border land between the two. If, on the other hand, the Eurafrican continent be more readily carried eastward, then instead of a zone of compression, we shall have a zone of tension which is not improbably the actual case. At all events, there is no well founded reason to expect a Cordilleran range to be developed along the eastern coast of the present Atlantic on the ground of differential rotation between the superficial layer of the earth's crust and the barysphere.

From elementary mechanics we see that the magnitude of the centrifugal force is directly proportional to the distance between the particle and the axis about which it rotates. In a given latitude the raised continental areas would therefore be affected to a greater extent than the sunken oceanic base. This, in part, accounts for the fact that the continents on the whole suffered deformation to a far greater extent and degree than the true oceanic floor. In fact, this differential effect is noticeable even in minor depressions.

The writer has attempted to show elsewhere[1] that so long as the stresses set up in the earth's crust by a presumptive increase of the earth's rotational speed are not completely relieved through internal deformation, the surplus centrifugal force will give rise to an unbalanced horizontal component which is nil at the poles and on the equator. Taking into consideration the present ellipticity of the earth, the maximum tangential force is exerted in latitude 44° 51′ 40″.

Now suppose that a given portion of the continental mass be thus pushed to a lower latitude it would not be able to keep pace with the eastward movement of its underlying barysphere, with the consequence of being slightly displaced towards the west. The latter effect is however almost negligible, as has been shown by Epstein.[2] We may therefore say that one of the immediate consequences that follow an increase of the earth's rotational speed is to urge the northern continental masses to move southward and southern continental masses northward. As the continental masses possess a definite strength, tangential stresses will be developed therein and stored up until the yielding point or ultimate strength is reached. Then a movement with a general tendency towards the equator will set in, provided that the upper layer of the continental mass as a whole could move uniformly. As a matter of fact, such uniform movement is impossible; for the distribution of continental mass is by no means uniform and the tangential forces operating in different latitudes are far from being equal. Such a struggle for the equator would then be necessarily accompanied by a certain amount of rotational movement subject to regional conditions.

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[1] J. S. Lee, op. cit., 216–21.

[2] P. S. Epstein, "Über die Polflucht der Continente," *Die Naturwissenschaften,* Heft 25, 1921, p. 502.

Being checked on the south-west by the less-affected Indian mass as well as by the foundered Gondwanaland, which probably formed a southern or rather south-western continuation of the present Indian Peninsula, Eastern Asia would be disposed to undergo a relatively greater displacement in its eastern part by shearing along the Pacific border. Hence results a clockwise rotation around Indo-Tibet. Similarly, Australia cannot move uniformly northward on account of the resistance offered by its north-eastern part now partially submerged under the Arafra Sea and by the mass of New Guinea, which is almost on the equator. West Australia, at least the upper stratum of West Australia, does not encounter such a resistance, and therefore is readily sheared northward. Consequently the whole of the Australian mass tends to rotate clockwise. Herein we find a cause for the development of the Rift Valley of South Australia.

The presence of the Mediterranean Basin, which is less affected by the rotational force, and the distribution of the land-mass of south-eastern Europe in the neighbourhood of the middle latitude where the tangential force reaches its maximum, provide the necessary conditions for the clockwise rotation of south-eastern Europe. This rotational movement seems to be all the more necessary when we know that western Europe has moved southward more or less as an independent unit.

North America possesses a degree of bilateral symmetry with reference to the longitude of 100° W. Had it not been for the presence of the mass of Alaska its upper layer would have shifted southward in a symmetrical manner; but with the attachment of the Alaskan mass high in the north-west where the tangential force is relatively small, the whole of North America is then hooked on, as it were, to the northern Pacific. The whole of that continent would be thus compelled to rotate clockwise.

The southern part of South America forms a rectangular triangle. One of the sides that contain the right angle coincides with the Pacific coast which runs almost meridionally. Eastward the land-mass continually recedes towards the lower latitudes. When that triangle presses itself northward through the horizontal component of the rotational force, the greatest tangential pressure is obviously exerted by its western part. The tendency would be to rotate the southern part of the continent clockwise.

Of all the large continents, South Africa is the only one that possesses the highest degree of bilateral symmetry; so it is the only continent in which we have failed to find any trace of rotational movement on a large scale.

These shearing movements administered by unequal and longitudinally directed forces in different parts of the continents are undoubtedly accelerated and modified by the vertical as well as horizontal shear due to the relative east or west movement between parts of the continental masses. The combined effect is particularly pronounced along the western border of the Americas, south-western border of Eastern Asia, and in the Rift Valleys of East Africa.

Having thus deduced the nature of the force that has given rise to the various shearing movements, the question now must be answered: how could the earth have periodically increased its speed of rotation? The tidal force cannot hasten up its speed, but tends to slow it down, though the latter effect may not be so far-reaching as is generally supposed.[1] So long as we are unable to discover some other astronomical cause which periodically forces the earth to rotate at a higher speed, the presumption is strong that that cause must be looked for in the behaviour of the earth itself. This presumption becomes a necessary logical issue when we know that the increase of speed originates from the barysphere, for which we have already obtained some evidence. It would then seem that we are left no alternative but to accept the condensation of the earth's mass as the only possible cause; for, in that case, the earth is bound to increase its velocity to comply with the principle of conservation of momentum.

The condensation of the earth's mass can be accomplished in a number of different ways: bodily contraction for one, segmental foundering of the oceanic base for another, and a possible gravitational differentiation in the deep interior for a third. Thus a common ground is provided for the exponents of various and apparently hostile theories.

The conception of tectonic evolution and revolution [2] fits in well with our conclusion. The evolutionary period is that during which mass-condensation gradually took place. A gradual increase of velocity of rotation follows the concentration of mass until a critical time is reached when the crust of the earth is no longer capable of sustaining the tangential stress thus set up. Revolution then breaks out with the net result that the upper strata of the continental masses, as a whole, are to some extent displaced to lower latitudes. While the accumulated stresses are being relieved through shearing movements, dynamic metamorphism, uplift of mountains, magmatic intrusion or extrusion, etc., a part of the surplus kinetic energy will be spent in imparting the requisite momentum to the displaced continental masses. The rotational velocity of the earth will be thereby slightly and temporarily lowered. This sudden relief of stresses together with a slight decrease of speed would result in a general relaxation or cessation of pressure. At the same time the interior of the earth probably slowly adjusts itself to a new figure appropriate to the altered rotation. Equilibrium would be once more established. A period of evolution recommences.

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[1] T. C. Chamberlin, F. R. Moulton, C. S. Slichter, etc., *The Tidal and other Problems*, Carnegie Inst., 1909.

[2] H. Stille, *Tektonische Evolutionen und Revolutionen in der Erdrinde*, Leipzig, 1913, pp. 10–24.

The mobile mass of the oceans ought to serve as a sensitive indicator for the inferred fluctuation of rotation. If the concentration of the earth's mass be due to the foundering of the oceanic base, then the depth of the ocean and consequently the volume of the ocean would be increased accordingly. This means that before an orogenic period the oceans would tend to recede from the continental areas. The facts however point to the contrary. If, on the other hand, the concentration of the earth's mass be due to a general contraction of the body of the earth while the ocean floor maintains its general depth, then during contraction, or prior to an orogenic period, the surplus oceanic water would necessarily find its way to the depressed areas on the continents. The result would be an extensive marine transgression. Since the mobile hydrosphere is undoubtedly more susceptible to the increase of the earth's rotational velocity than the lithosphere, the marine transgression would be more pronounced in low latitudes before the commencement of the following orogenic movements, the actual extent of transgression being subject to the control of the gravitational potential and local topographic conditions; whereas soon after the movements, the rotational velocity being slightly lowered, marine transgression would take place in the polar regions.

This theoretical deduction raises the whole problem of marine transgressions in the geological past. The subject is too vast to be dealt with here. We may however briefly note the relative order of the more marked transgressions and the intervening orogenic movements. Thus the extensive Devonian transgression over the Americas and Eurasia was followed by a powerful orogeny characterized by the Tianshan movement in Central Asia; so was the Upper Carboniferous or Uralian transgression by the Hercynian movement, the Upper Cretaceous transgression by the Laramide movement, and the Lutetian transgression by the mid and late Tertiary movements. Directly after these movements, fairly large areas in the Arctic were submerged under marine water. These are the Lower Carboniferous in northern Eurasia and the northern part of North America, Permo-Carboniferous in Siberia, Thanetian in northern Europe and probably in western Siberia, and early Pleistocene in northern Eurasia. With each episode of extensive movement closes a geological cycle. More detailed investigation shows that at least nine of such cycles are recognizable since the beginning of the Mesozoic Era.[1] The succession of events in those cycles on the whole agrees remarkably well with our expectation.

We are therefore enabled to conclude that bodily contraction of the earth is the most probable cause for periodic increase of its rotational speed. From the essentially unaltered position of the highly deformed zones, the continued development of the grander tectonic units and the distribution of marked transgressions from the earliest geological time down to the present day, we are further led to doubt the possibility throughout geological time of any extensive migration of the geographical poles, or of any extensive drift of the continents *en bloc* other than that ascribable to the probable widening of the Atlantic.

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[1] J. S. Lee, "The Canon of Marine Transgression in Post Palaeozoic Times," *Bull. Geol. Soc. China*, vol. vii, No. 1, 1928, pp. 81–128.

I am deeply indebted to Professor W. S. Boulton, D.Sc., for his valuable suggestions and persistent care in seeing the whole paper through the press. For any possible mistakes the writer alone must however remain responsible. Because of my inability to attend to the proofs somewhat heavier work than usual has been thrown on the Editor of the Geological Magazine, Dr. R. H. Rastall, to whom I wish to tender my thanks.

RECENT PUBLICATIONS.

Geological Survey of the Union of South Africa.

The Geology of the Major Portion of East Griqualand. By A. L. du Toit. Explanation of Cape Sheet 35 (Matatiele) with map, 3·75 English miles to 1 inch.

The Geology of the Postmasburg Manganese Deposits. By L. T. Nel, with map in two sheets, scale 1 : 59,501.

The Geology of the Country Surrounding Pretoria. By H. Kynaston, revised by L. J. Krige and B. V. Lombard. Explanation of Sheet 1 (New Series) with map, scale 2·347 miles to 1 inch. Government Printers, Pretoria, 1929.

Geological Survey of Southern Rhodesia.

The Geology of the Gaika Gold Mine, Que Que, Southern Rhodesia. Bulletin 14. By S. C. Morgan. The Rhodesian Printing and Publishing Co., Ltd., Salisbury, 1929.

An Outline of the Geology of Southern Rhodesia, 2nd edit. Short Report, No. 24. By H. B. Maufe, Director, Geological Survey. 1929.

Tanganyika Territory Geological Survey.

Annual Report, 1928, Government Printer, Dar es Salaam, 1929.

State of Idaho Bureau of Mines and Geology.

Geology and Silver Ore Deposits of the Pend, Oreille District, Idaho. By E. Sampson, University of Idaho, Moscow, Idaho, 1928.

University of California Publications.

Bulletin of the Department of Geological Sciences, vol. xviii, 1929 :—
Geology of the Marysville Buttes, by Howel Williams.
Metallization from Basic Magmas. By C. D. Hulin.

REVIEWS.

THE EVOLUTION OF THE IGNEOUS ROCKS. By N. L. BOWEN. Oxford University Press. 1928. 23*s*.

THE work of the Geophysical Laboratory of the Carnegie Institute has given a distinctive character to much of the progress made in geology during the first quarter of the twentieth century. In a sense this work follows as a natural sequel to the researches of Hall, Daubrée and other pioneers—but regard for the past need in no way lessen our pride in the present.

Let us recognize at once that only a few of the data obtained in the Geophysical Laboratory can be applied directly to the solution of petrological problems. The wise policy has been adopted of experimenting under simplified conditions so as to obtain definitely interpretable results. Thus many wide gaps still separate laboratory experience from field observation; but in certain cases promising foundations have been laid for the support of connecting hypotheses. In Dr. Bowen of the Geophysical Laboratory we find a bridge-builder determined to link up experimental physics with petrogenesis. His equipment for the task is ideal. His main theses have already been published in a series of well-known papers; they are now brought together and co-ordinated in a volume based upon a course of lectures delivered in 1927 to advanced students at Princeton University.

A review of Bowen's book is an onerous task. The whole requires consecutive reading and re-reading. Doubtless its demonstrations and speculations have great educational value. Probably too they will serve as an incentive to fruitful research. One foresees that the pleasure of proving their author wrong in this or that particular will provide a healthy stimulus to many a petrologist. It is to be hoped that those who establish corrections will also consider how far their results modify the general principles involved. Sometimes a correction is a great source of strength.

It is feared that the following rather disconnected jottings will convey only a very inadequate impression of the matter and method of the original.

For various reasons basaltic magma is recognized as the parent stock of igneous rocks in general. Differentiation is accepted in explanation of the relationship that can often be traced among the diverse products of a single rock association. It is to be noted that such relationship can only be appreciated when one rock association is compared with another.

Fractional crystallization, dependent upon relative movement of crystals with respect to residual magma, is adopted in explanation of differentiation. The postulated movement is supposed in some cases to be determined directly by gravity and in others by deformation. Bowen claims (1) that fractional crystallization is a potential factor which may on occasion be expected to lead to important differentiation, (2) that its anticipated products agree sufficiently closely, both positively and negatively, with known igneous rocks, and (3) that no other factor can be named for which (1) and (2) hold true.

In regard to (2), Bowen points out that binary igneous rocks are only found where their component minerals are not widely separated in the crystallization sequence ; for instance, no known igneous rock is composed wholly of very basic plagioclase and quartz. In regard to (3) he quotes Greig's experiments on immiscible silicate melts, and shows that the phenomenon is restricted to melts that differ, in quantitative composition, from all analyzed igneous rocks.

After discussing crystallization of several melts with a view to illustrating such matters as eutectics, incongruent melting and solid solution, he defines his *reaction principle* with regard to both discontinuous and continuous reaction series. Reaction between early crystals and residual magma may be checked either by bodily removal of the crystals or by their cloaking through zonal deposition. One may therefore agree that the reaction principle confers great elasticity upon differentiation.

Another very important feature of Bowen's philosophy is his distinction between igneous rocks which have crystallized from a completely liquid condition and others which owe certain peculiarities of composition to concentration of crystals. He thinks, for instance, that dunites and anorthosites belong to the latter class. In this connection he is loth to admit important remelting of early crystals. Quite probably this will lead to much misplaced criticism, for there may be a tendency to overlook the limits of remelting which Bowen himself accepts as possible (pp. 141, 276). For instance, he is quite prepared for the discovery of a non-porphyritic basaltic glass with normative felspar as basic as Ab_1An_2, although he certainly claims that the great majority of basalts of this composition have never been completely liquid.

The discussion of possible reactions between magma and inclusions is very interesting. It is definitely recognized that some norites may have resulted from interaction of basaltic magma with aluminous sediment, and that some alkali rocks may have been assisted in their formation by assimilation of limestone.

This brings us to Bowen's explanations of alkali rocks. In one of them he suggests that leucite originates by virtue of the incongruent melting point of orthoclase, which, under certain conditions, allows of the precipitation of leucite from magmas that retain a little normative quartz. Leucite formation, he thinks, is often a step towards nepheline production, by virtue of the reaction that leads to the development of pseudo-leucite. Another of his suggestions in regard to the formation of felspathoids depends upon fractional resorption of hornblende or biotite on sinking into relatively hot layers. These speculations are, it should be mentioned, relegated to Part II of the book, because they rest on a relatively insecure foundation. Volatile components are also treated in Part II, but in this case it is because Bowen regards them as endowed with little evolutionary importance.

Let us here return to a very interesting point dealt with at an early stage in the book. It is left an open question in the Mull Memoir (1924) whether the passage from the Mull Plateau magma type to the Mull Central Non-porphyritic magma type was accomplished with or without assimilation of sediment. The doleritic crystallization of the former is olivine-rich and often carries analcite; that of the latter is olivine-poor or olivine-free and carries quartz. Bowen gives a delightful geometrical solution of the problem and shows that fractional crystallization provides a completely satisfactory answer, while assimilation (unless accompanied by differentiation) fails altogether. It is only fair to recall that the present writer was primarily responsible for adopting an agnostic attitude on this question in the Mull Memoir, and that Thomas has already embraced fractional crystallization as the true explanation (*Rep. Brit. Ass.*, 1927).

Perhaps one or two suggestions may now be offered for the sake of future editions. In the first place the price is sufficiently high to deter purchasers. In the second, though the book is capitally written, it is difficult to digest, and yet a very little additional explanation would bring it within reach of a considerably wider circle of interested readers. A few properties of triangular graphs might well be given as a foreword, illustrated by reference to existing figures—there would be no need for proofs as these are sufficiently self-evident. Another improvement would be the transfer of the memorandum of chemical compositions from the end to the beginning of the book. In its present position it is apt to be overlooked. But let us say no more about such trifles. The author is entitled to our heartiest congratulations upon the completion of a very characteristic and valuable contribution to petrological science.

E. B. Bailey.

Disrupted Strata. By M. H. Haddock. pp. vi + 104, 7 plates.
London: Crosby Lockwood & Son, 1929. Price 16*s.* net.

For those who may be misled by the title of this book, let us say at once that it is a mathematical exegesis on faulting. As the first example of such in book form, it is entitled to our respect; as a text book on "faulting . . . from the standpoint of the mine surveyor and stratigraphist (*sic*)" we fear it will fail dismally.

The author is fully aware of the stigma that geologists will attach to it on the score of its mathematical complexity, but in this respect he has some measure of our sympathy. The present writer has found that, given the accuracy of the formulae in terms of functions that can be readily measured in the field, quite as complicated expressions as those here developed can be fairly quickly evaluated by means of a slide rule and with only a small percentage error.

A far more serious defect in our opinion lies in the terminology of the book, as evidenced by the author's reckless introduction of new terms and perversion of the meaning of terms of long standing. He starts on the assumption that the movement along a fault plane does not usually take place in the direction of the maximum dip of the fault, but obliquely to it. This necessitates the introduction (chiefly from American authors) of a large number of new terms of which "dip slip", "strike slip", "net shift", "perpendicular displacement" are only examples. The author will have our sympathy in claiming that the word "hade" is superfluous, and in everywhere speaking of the "dip" of the fault, but we fear that the term is too strongly established in geological literature to go down without a struggle.

The author's classification of faults is rendered abortive *ab initio* by his calling all faults except those of the rotational type, "thrusts," though in the subheadings he uses the terms "dip and strike faults", "dip and strike thrusts", without discriminating between them. Now the term "thrust" has acquired such precise significance in British geological literature that it should not be used in a totally different sense. The terms "backthrust" and "forethrust" (introduced on page 10, but not defined till page 36) are also quite new to this country. The sub-heading "Diagonal faults" is superfluous. A fault is not expected to lie in the precise direction of the full dip or full strike of the strata, but the bounding position of 45° will always determine whether it should be classified as a dip or strike fault. The heading "Rotational faults" is of doubtful value. Every fault must *per se* end at some point where its throw becomes zero. A rotational fault on a small scale, therefore, is equivalent to a fault with throw varying along its length; and it is doubtful if rotational faulting on a larger scale than this exists in nature. Such movement as that pictured in plate 7 is not true faulting, since the dislocated blocks no longer remain in contact.

In the section dealing with rotational faults the use of the word "pole" for an axis of rotation is contrary to all mathematical canons. The term "surface strike" (p. 41) has no meaning whatever.

The author seems to have gone out of his way to make the book as abstruse as possible. An initial error in determining the angle daQ invalidates all but two of the formulae developed on page 9. This might have been avoided if the diagrams on plate 1 had been drawn in two dimensions instead of three. The problem occupying pages 41–44 and folding plate 3 can be worked out in twenty lines by co-ordinate geometry.

The larger diagrams are as clear as their extreme complexity will allow; many of the smaller ones, such as those on plate 2, are too obscure to check the constructions. The author's system of notation is confusing in the extreme.

The printer has grappled manfully with his uphill task; but such grammatical monstrosities as coupling the plural words "strata" and "data" with singular verbs, and the typographical hieroglyphics on page 44 should never have escaped the eye of a vigilant proof-reader.

Our feelings on laying down this book are those of the poet:—"Parturiunt montes, nascitur ridiculus mus." At any rate the book will need to be very largely rewritten in plain and precise English before it can ever hope to take its place on our shelves as a standard geological work of reference.

K. W. E.

THE GEOLOGY OF PETROLEUM AND NATURAL GAS. By E. R. LILLEY, Sc.D. London: Chapman and Hall, Ltd., 1928. 30*s*. net.

THE body of literature concerning petroleum has reached enormous proportions in the short history—little more than half a century—of this very important substance, and even that part of it concerned only with the geological aspect of its occurrence has grown to such a size that it is almost impossible for the individual geologist specializing in petroleum to keep abreast of it, as Professor Lilley points out in his preface. He has therefore written this book, in which he summarizes the more important contributions in statements of principles and prominent illustrative examples. While it seems a pity that only very brief references and few illustrations are drawn from parts of the world other than the United States, this is perhaps only natural, seeing that the birth of the industry took place in that country, and that the greatest development of petroleum mining has there been effected.

It is not generally realized that organized scientific control of well siting—that is, by the employment of geological science—was practically unknown thirty years ago. The earliest wells in Pennsylvania were drilled on seepages and the operators, in extending their activities in areas beyond those where seepages occurred, based their locations chiefly on previous experiences, such as their recognition of the occurrence of oil in connection with certain topographical features or along extensions of lines joining up producing areas, though the geological reasons were not appreciated. The prevalence of dry holes, and, perhaps of even more insistence, the search for petroleum in all parts of the world involving expensive drilling, demanded the employment of every means to ensure success and to minimize the chances of fruitless expense. The earlier "petroleum geologist" was generally somewhat lightly equipped with but few principles to guide him, and, it is to be feared, in many cases but lightly equipped also with geological knowledge. Professor Lilley rightly expects that a much higher order of training is necessary, since the occurrence of oil in complex structures and areas distant from seepages demands greater scientific knowledge for their elucidation. His remarks on errors of mapping in Chapter IX are much to the point.

This book, then, can confidently be recommended as one which treats the subject in an ordered and scientific spirit. Nine chapters are concerned with the properties and origin of petroleum and allied substances, reservoir rocks and structures, and geological distribution. Further chapters describe in sufficient detail examples of oil pools illustrative of the principles laid down, the types of accumulations being divided into those controlled by folding, faulting, porosity, variations, complex factors and salt domes. The chapter on this last type is particularly interesting reading, and a lucid account of the various theories concerning a much discussed subject. There is a short but clear summary at the end of each of these chapters. In chapter xvi, the faulting shown in Figs. 161 and 165 is difficult to understand, although these figures are presumably somewhat diagrammatic.

The book is well and fully illustrated with figures and tables drawn from many sources. Several of the tables, however, might be omitted as being hardly necessary, and in a number of instances, such as Figs. 36, 50, 90, and table 52, the type is so small as to be read only with much strain to the eyes. The production is good, and there is a full index. Typographical errors are very few, the only ones noted being one on p. 111, and the absence of page references on p. 293, and of a legend reference in Fig. 166.

C. B. B.

CORRESPONDENCE.

GEOLOGY OF CYPRUS.

Sir,—Since the publication of my paper on Cyprus in the October number of the Geological Magazine, Dr. W. A. Macfadyen has called my attention to a paper by R. Russell, C.E., on the geology of the island, which was published in the *Report of the British Association for* 1881, *York Meeting*, pp. 640–2. This valuable though brief communication is of special interest, inasmuch as it maintains that the relations of the Idalian beds to the igneous rocks are those which I have independently been led to adopt.

F. R. C. Reed.